NOTE TO VENDORS

- As part of requested risk mitigation studies requested by NOAA, multiple grating point designs were performed by MIT – Lincoln Laboratory.
- Suggestions were made to NOAA for the best way to meet the required retrieval performance with a grating.
- These suggestions are contained in the subsequent presentations.
- Although earlier work by MIT- LL is mentioned, the following slides are self-contained and describe the grating point design.

ABS Grating Design Overview

David Weitz

GOES Quarterly Review

20 June 2002

Outline

- Grating spectrometer review
- Design iterations
- Present status and recommendations

Grating Spectrometer Review

- **Key features**
  - Extract spectral information with diffraction gratings
  - Use rectangular detector arrays to simultaneously image spatial information
  - Common scanning optics and telescope for all bands
- **Operationally, a grating-based ABS would scan a linear ground FOV over the coverage area**
- **The spectrometer itself would have no moving parts**

Design Iteration Process

- First MIT/LL grating notional design
- Presented to NOAA on 11/7/01
- 4 gratings:
  - 2 LW, 1 MW, 1 SW
- Conceptually, the design was appealing
- Key problem: design didn't meet spectral resolution requirements as currently delineated in operational requirements document(s)

Design Iteration Process -- 2

- Second MIT/LL grating design
- Presented to NOAA on 3/6/02
- 6 gratings:
  - 3 LW, 2 MW, 1 SW
- Design was mechanically complex (e.g. non-planar layout, etc), but appeared to have requisite spectral resolution
- A detailed radiometric model, however, indicated that S/N was too low in longest LW band
- There may also have been slit imaging issues with the out-of-plane paths

Design Iteration Process -- 3

- **Latest MIT/LL grating design**
- **7 gratings:**
  - **3 LW, 2 MW, 2 SW**
- **Increase S/N by increasing effective slit width (& hence pixel width)**
- **Use multiple slits to avoid detector redundancies from dichroic overlap regions**
- **Use multiple sub-reads per integration period to accommodate pixel well-depth constraint**
- **We've explored numerous variations on a theme to reach present design incarnation**
  - **E.g. ~200 optical design files**

Grating Design Status & Recommendations

- **Present grating design is complex**
- **Technical challenges exist over entire design space**
- **Would not recommend this particular design as viable for production/flight**
  - **Two other concept grating designs (non-MIT/LL) also don't appear viable when evaluated as end-to-end solutions**
- **Exploration of technical issues has been a productive exercise – highlights key design challenges and drivers**
  - **Relevant for understanding any grating proposals**
- **Subsequent talks will discuss these design drivers and implementation details**

Summary

- MIT/LL has nearly completed a point-design study for a grating-based ABS instrument
- Design has evolved over numerous iterations
- Key drivers have been spectral resolution and band coverage, S/N, and scan coverage time
- These constraints are coupled, necessitating an iterative optimization procedure
- Present grating design is probably not suitable for manufacture/flight, but there may exist a viable solution

Spectral and Temporal Design Drivers

Monica Coakley

Danette Ryan-Howard

NOAA Quarterly

June 20, 2002

Acknowledgements: Allen Huang

Outline

- Background: wavelength vs. wavenumber
- Physical Drivers: FPAs, Beamsplitter Coatings, and Flux
- Exploring Grating Spectral Coverage and Resolution
- Temporal Design Drivers
- Scan plan
- Further Implications for FPA
- Summary

Background: Wavelength vs. Wavenumber

For interferometer

Waveband (cm^{-1})	Wavelength (um)	Unapodized spectral resolution (cm^{-1})	Number of bins (1840)
650 – 1200	15.38 – 8.33	0.625	880
1650 – 2250	6.06 – 4.44	0.625	960

- **ABS was originally conceived as a scanning Michelson interferometer**
  - **is now described by parameters above**
  - **spectral resolution element is specified in wavenumbers (cm^{-1}).**
  - ➔ **1840 spectral elements**
- **For a dispersive system, the spectral resolution element**
  - **is constant in wavelength across the spectral region**
  - **is not constant in wavenumber across the across the spectral region**
  - **Initial estimate ~1840 spectral elements**

Outline

- Background: wavelength vs. wavenumber
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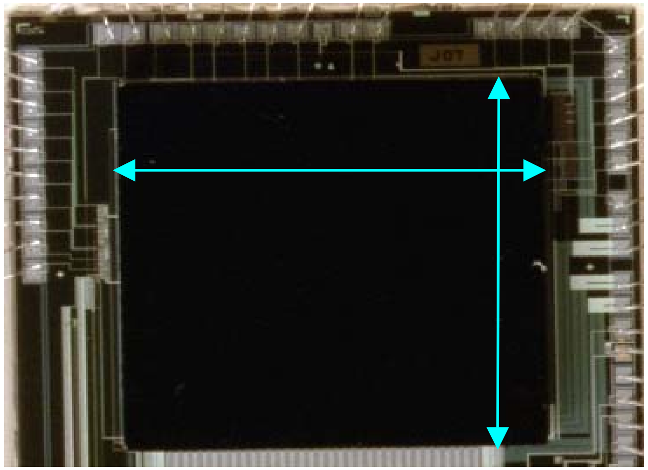
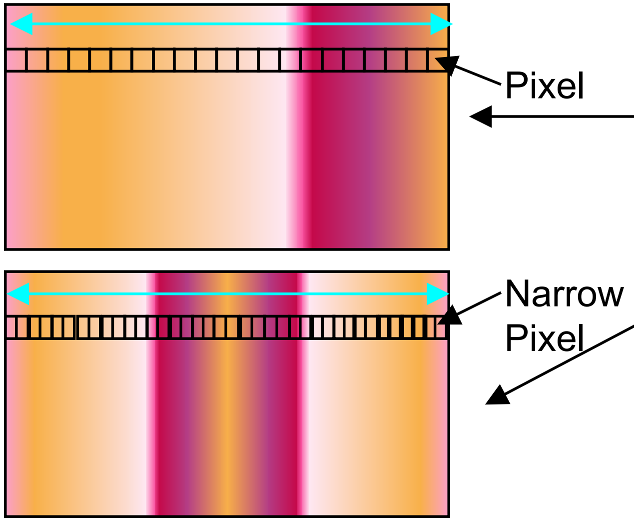
Physical Drivers: FPAs



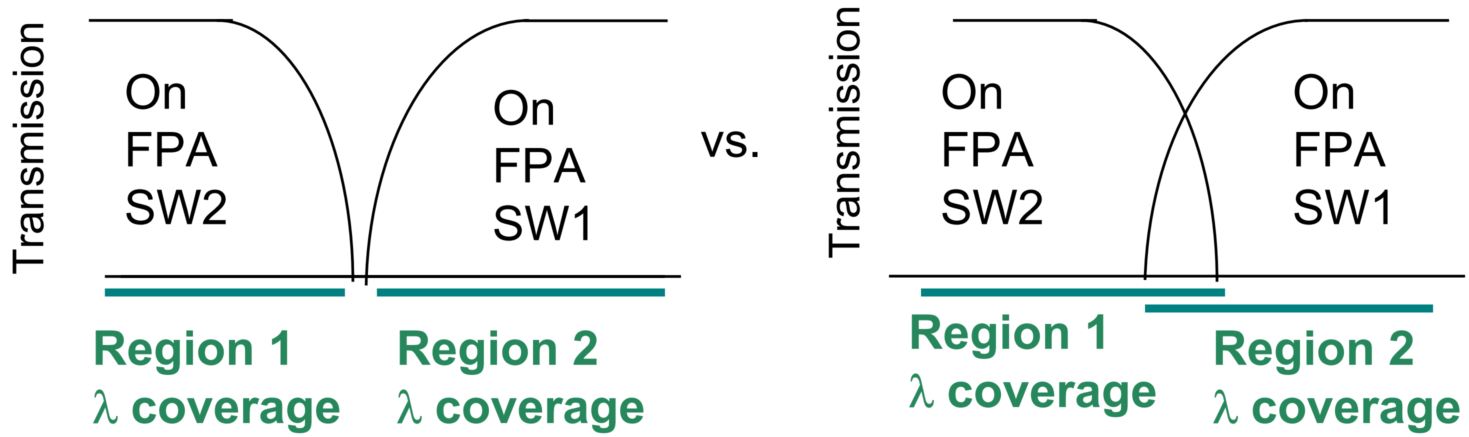


Spectrum projected onto FPA

- **Physical limitation in manufacturing processes <u>currently</u> place limitation on overall array dimensions.**
- **Thus multiple FPAs are required to cover the ~1800 to ~2000 elements of the IR spectrum.**
- **The product of the pixel pitch and the number of spectral elements for a grating spectrometer FPA is constrained to about 1.75 cm. Thus:**
  - **60 um pitch gives ~ 290 spectral elements.**
  - **28 um pitch gives ~ 620 spectral elements (yielded insufficient flux).**
  - **Chosen: 55 um pitch gives 313 pixels, covering 290 spectral elements and accommodation for known curvature of the field (total: 2030 elements).**

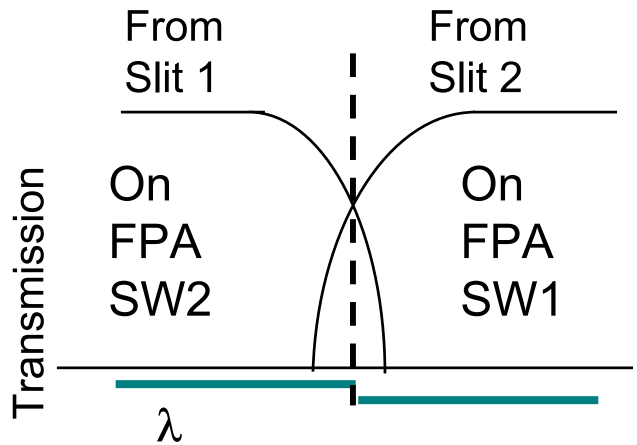
Physical Drivers: Beamsplitter coatings

- **To avoid gaps in spectral coverage between spectral regions, the wavelengths at the limits of one spectral region must be made to overlap two grating-FPA assemblies.**



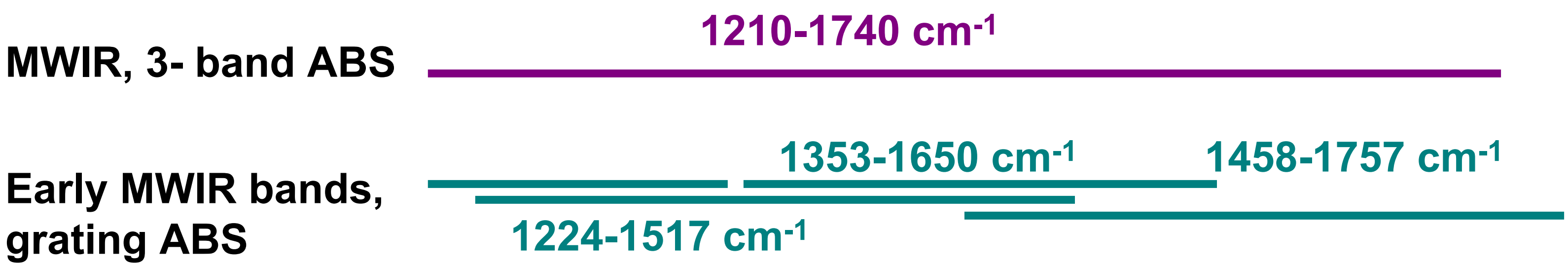
- **Effectively increases the total number of spectral elements**
  - **to > 1840 (assuming no redundancy).**
- **Increases the number of FPAs (and the number of gratings)**

Physical Drivers: Beamsplitter coatings and flux



- **The total number of spectral elements can be minimized by minimizing the spectral overlap between gratings.**
- **Multiple slits**
  - **can eliminate the need for spectral overlap of spectral regions from two different slits**
  - **can increase flux in-band by decreasing the number of beamsplitters**
  - **Are limited in number by their physical size in a small area**
- **Three slits were chosen**
  - **Longest spectral region has one slit, second longest has third slit, all other spectral regions employ second (middle) slit**

Physical Drivers: Beamsplitter coatings and flux



- Plot shows coverage comparison for an early set of gratings (green bars and labels) and the 3-band ABS MWIR (purple bar and label).
- Initial grating overlap choice of 0.8 um
  - Is realistic and conservative and in the LWIR
  - Leads to unacceptable multiple overlaps in the MWIR (as shown above) and in the SWIR.
- Overlap of 0.3 um finally chosen (based on real coatings)

Grating ABS: Multiple slits and overlaps explored

	3-band ABS (to 2720 cm^-1) and 60 um pixels
3 slits, regions have 0.8 um overlap	10 gratings
3 slits, regions have 0.5 um overlap	9 gratings
3 slits, regions have 0.3 um overlap	8 gratings (full resolution) 7 gratings (with 2*res from 950-1210cm^{-1}) and 0.5*res in SWIR
4 slits, regions have 0.8 um overlap	10 gratings
4 slits, regions have 0.3 um overlap	7 gratings

- Choosing 3 slits and 0.3 um overlap
  - yielded a minimum of 8 gratings at full resolution
  - was very challenging optical design
- Employing science-based resolution reduction can reduce optical design risk by requiring 7 gratings (with anticipated performance at least as good as 3-band ABS)

Outline

- Background: wavelength vs. wavenumber
- Physical Drivers: FPAs, Beamsplitter Coatings, and Flux
- ➢ Exploring Grating Spectral Coverage and Resolution
- Temporal Design Drivers
- Scan plan
- Further Implications for FPA
- Summary

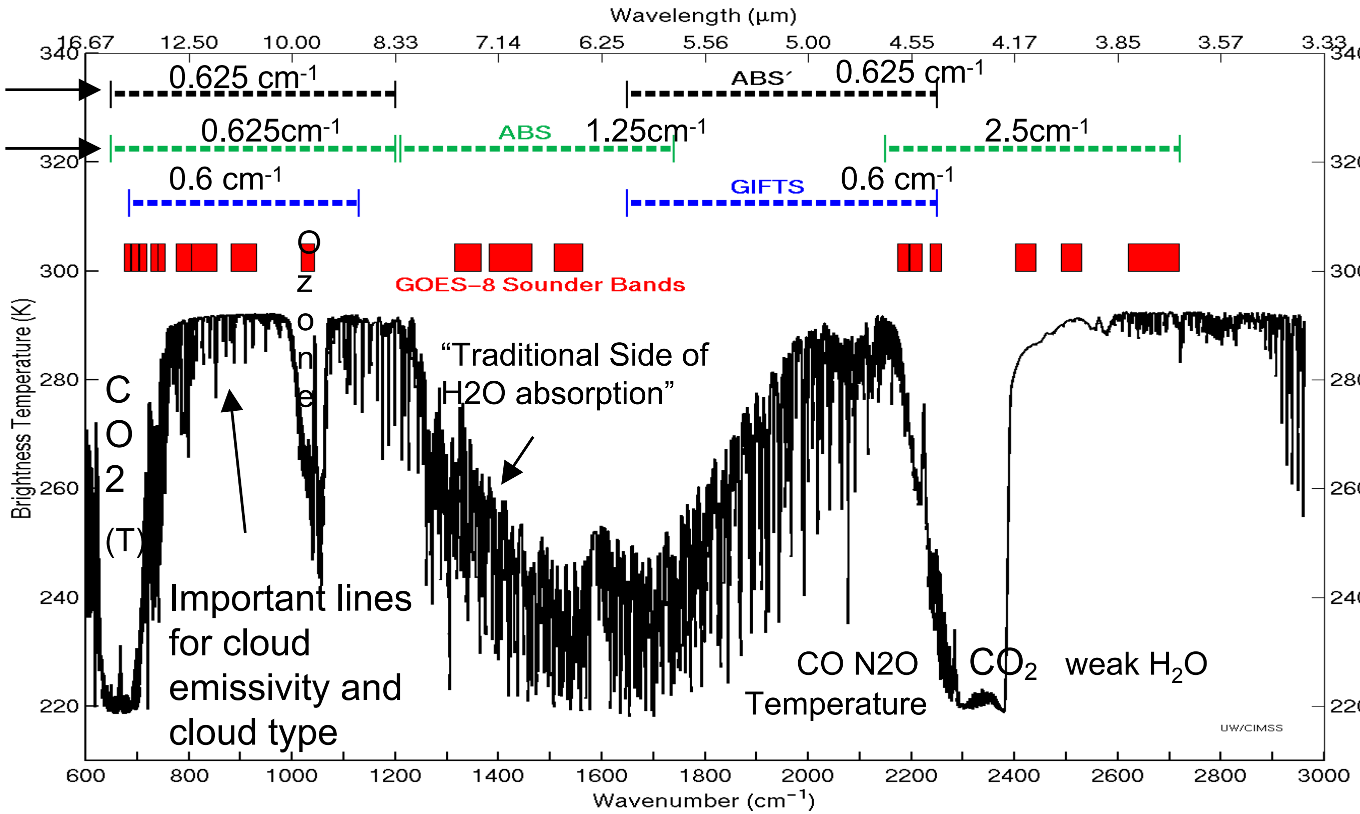
Grating spectral resolution choices

- For a dispersive system, the spectral resolution element
  - is constant in wavelength across the spectral region
  - is not constant in wavenumber across the across the spectral region
- Thus to meet the wavenumber (cm^{-1}) resolution requirement, the wavelength (um) resolution is chosen at one point <u>either</u>
  - to meet the old requirement for every point in the band
    - yields more spectral elements
  - to meet the resolution truly needed for the observations
    - yields fewer spectral elements

Exploring grating spectral resolution and spectral region break choices

2-band ABS

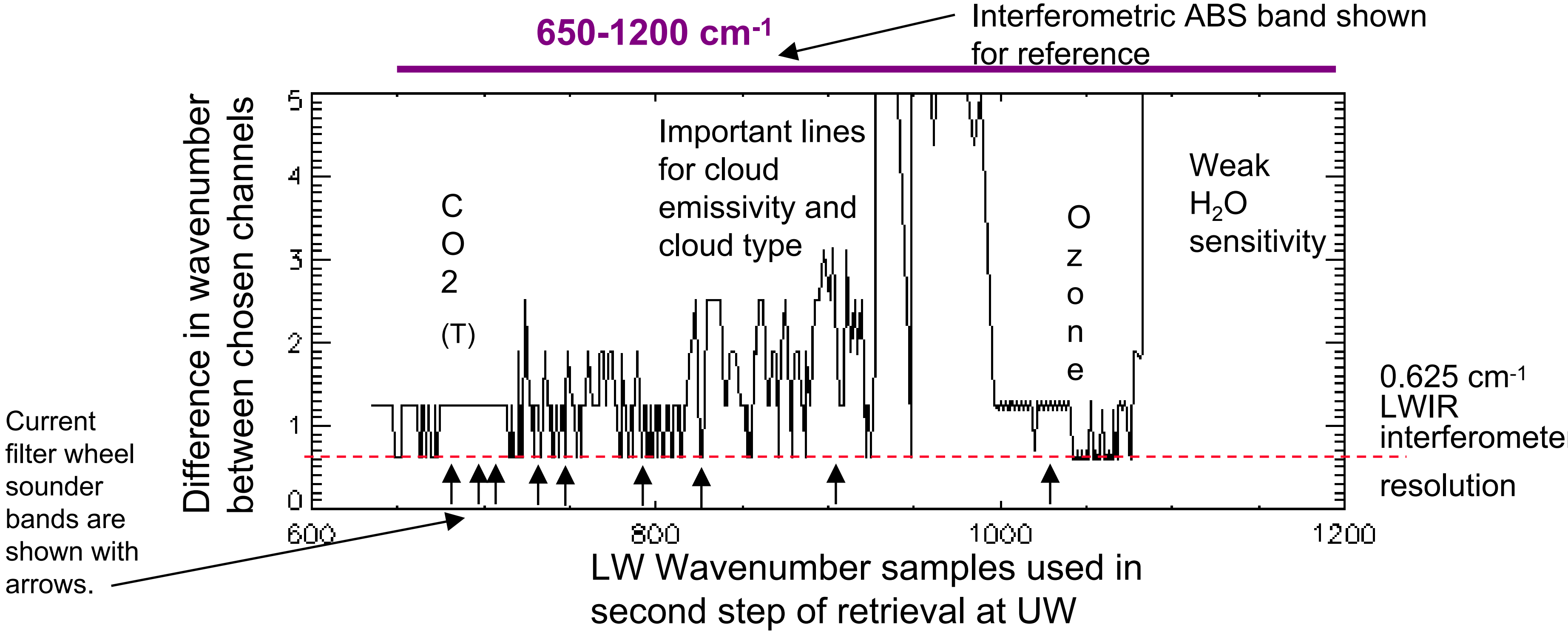
3-band ABS



Plot courtesy of Tim Schmit

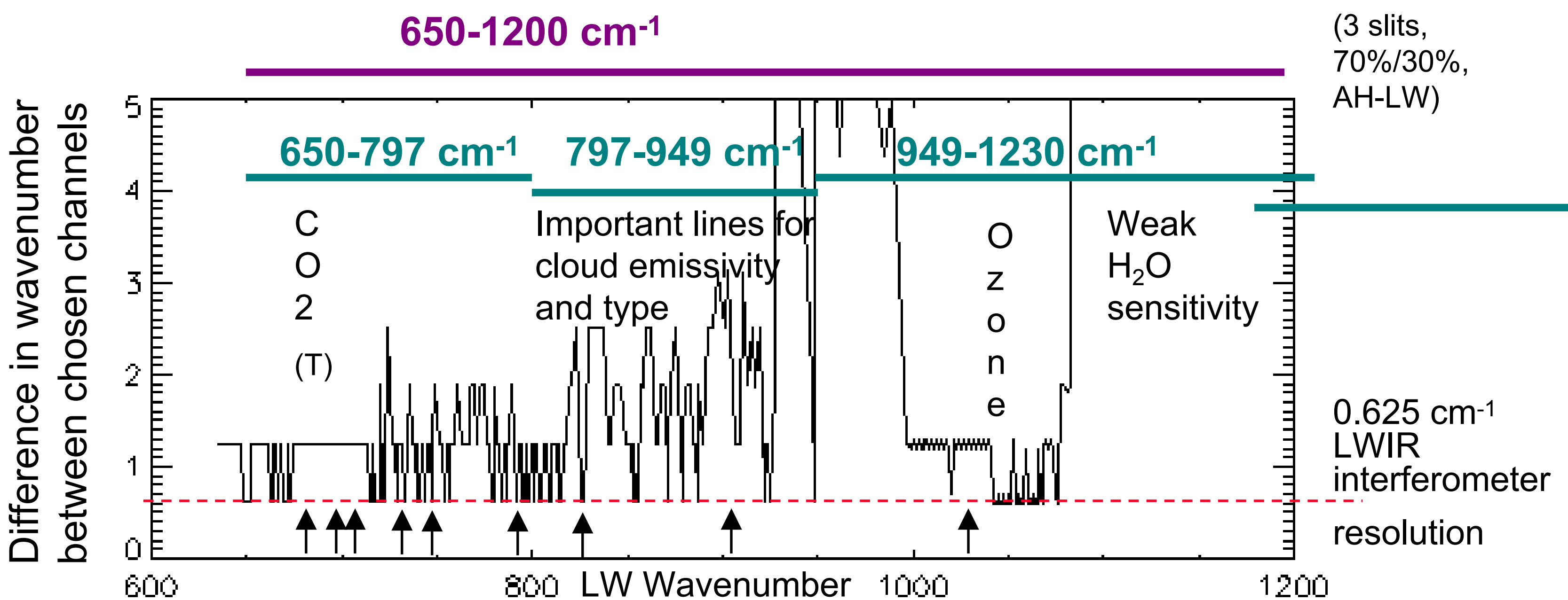
- **Brightness temperature spectrum shown for reference**
- **For determining region breaks and exact resolution, it is helpful to know where the highest resolution is employed in the retrievals.**
  - **Retrieval first guess typically employs all channels**
  - **Subsequent physical retrieval employs only selected channels.**

LWIR channels used in second step of retrieval can indicate best spectral breaks



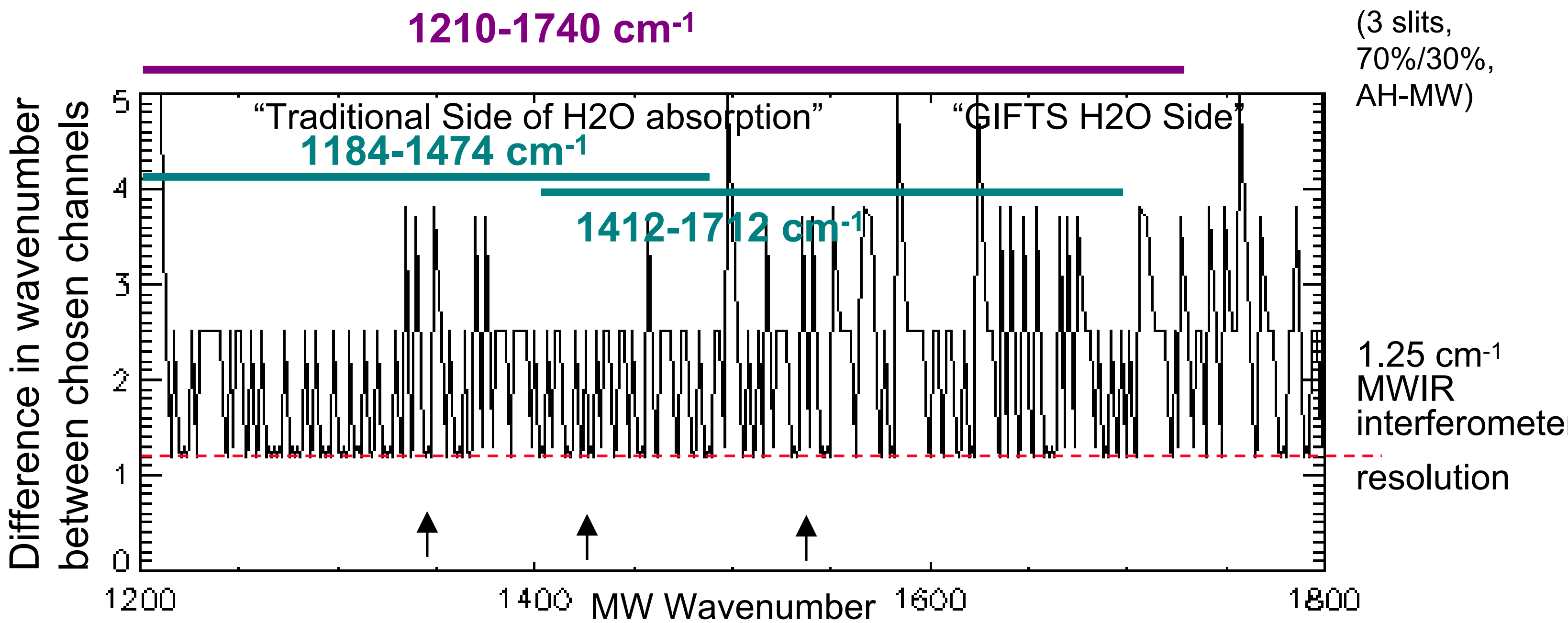
- **Plot shows difference in wavenumbers between LWIR semi-optimal spectral channels**
  - **chosen by Allen Huang (UW-CIMMS)**
  - **used during the second step of their retrieval process at UW-CIMMS.**
- **The highest resolution in the band is utilized in the interferometer ABS retrieval when the difference touches the dashed line.**

Proposed LWIR minimum grating configuration based on underlying science



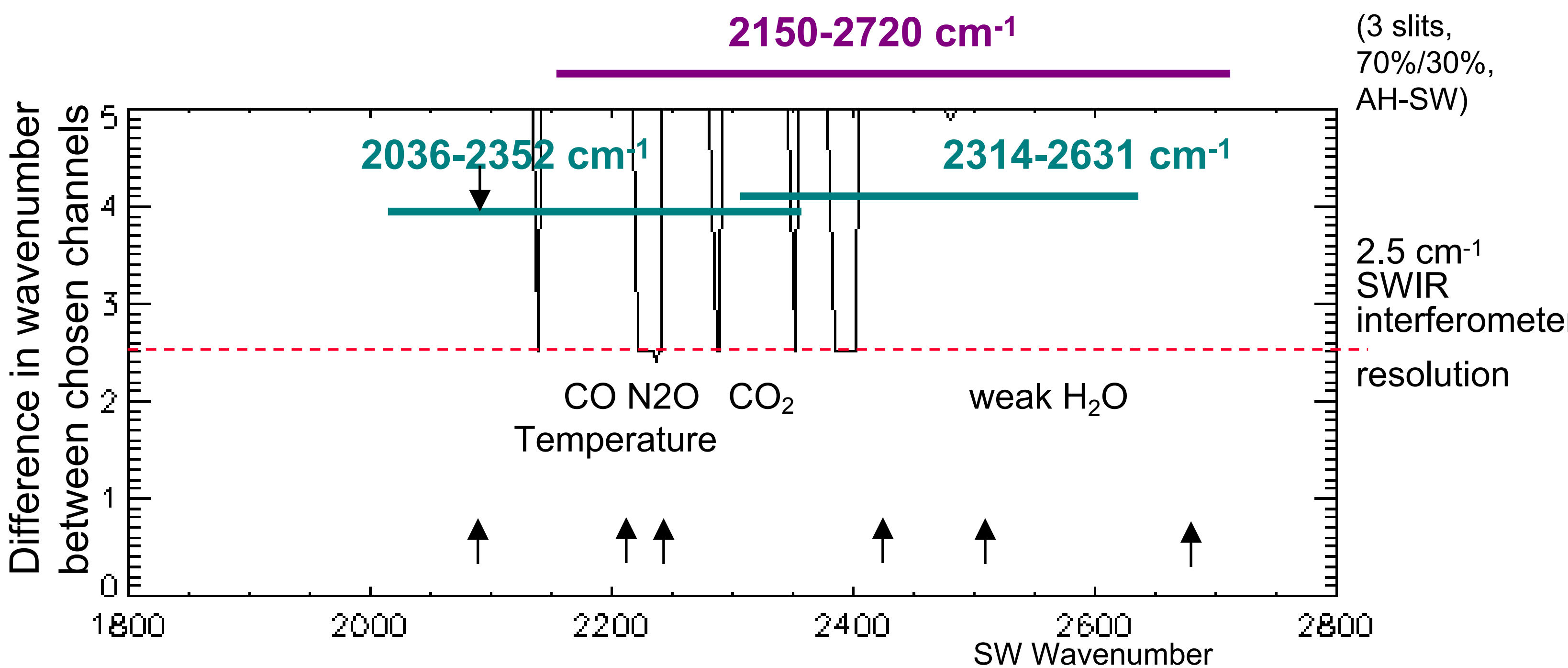
- Spectral region "LW1" covering 650-797 cm^{-1}
  - 0.625 cm^{-1} at the shortwave side of the region, better towards longer wavelengths
  - provides temperature information at the required resolution of the CO_2 lines.
- Spectral region "LW2" covering 797-949 cm^{-1}
  - 0.625 cm^{-1} at the shortwave side of the region, better towards longer wavelengths
  - Sharp features in the LW2 region are important for the retrievals.
- Spectral region "LW3" covering 949-1230 cm^{-1}
  - 1.25 cm^{-1} at its shortwave side, better towards longer wavelengths
  - ozone is not resolved spectrally even at 0.625 cm^{-1}.

Proposed MWIR minimum grating configuration based on underlying science



- **Spectral region "MW1" covering 1184-1474 cm^{-1}**
  - **resolution set at 1.25 cm-1 at the shortwave side, better towards longer wavelengths**
  - **provides water vapor information at resolution between 3-band and 2-band ABS.**
  - **Addition of faint SW water lines should enhance overall water vapor (Allen Huang).**
- **Spectral region "MW2" covering 1412-1712 cm^{-1}**
  - **resolution set at 1.25 cm-1 at the shortwave side of the region, better longer**
  - **provides water vapor information at resolution between 3-band and 2-band ABS.**

<u>Proposed</u> SWIR minimum grating configuration based on underlying science



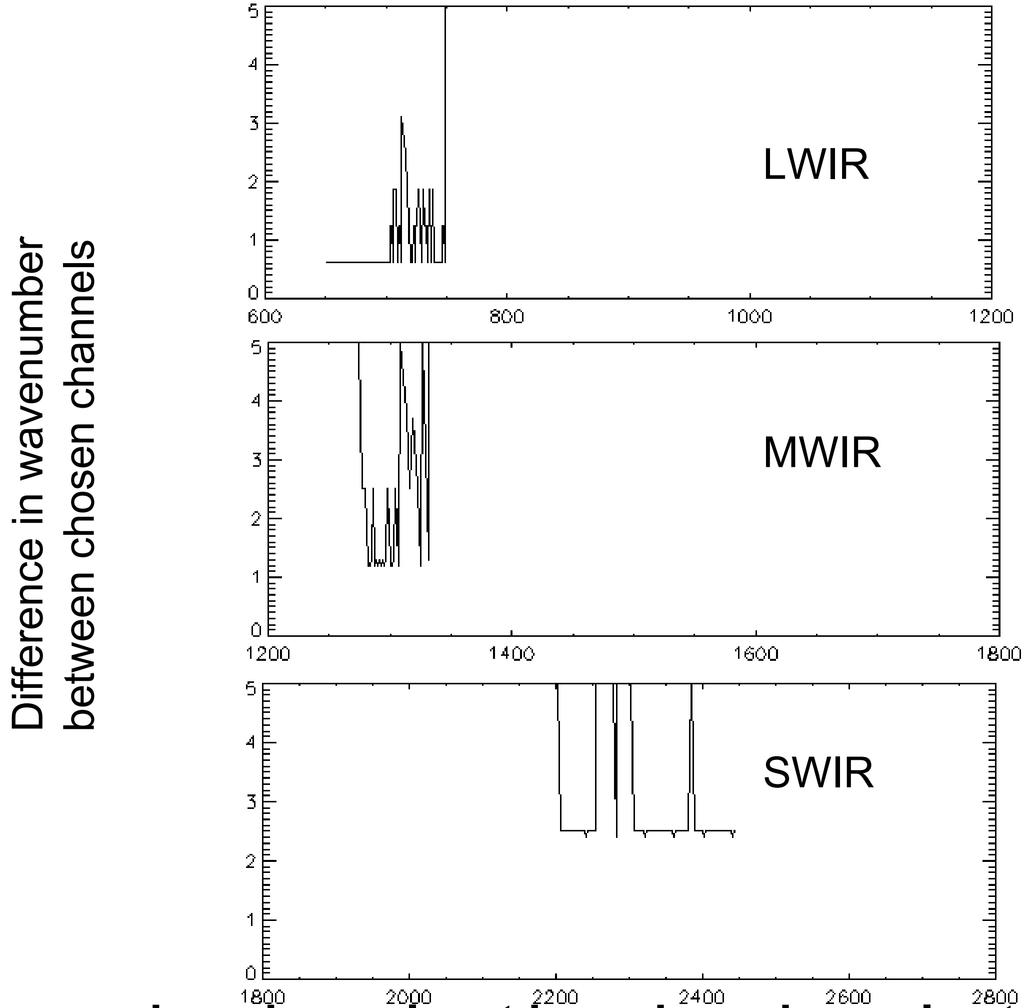
- **Spectral region "SW1" covering 2036-2352 cm^{-1}**
  - **resolution set at 1.25 cm-1 at the shortwave side of the region, better longer**
  - **provides temperature information using resolution 2x better than the 3-band ABS.**
- **Spectral region "SW2" covering 2314-2631 cm^{-1}**
  - **resolution set at 1.25 cm-1 at the shortwave side of the region, better longer**
  - **provides H2O (weak lines) information using resolution 2xbetter the 3-band ABS.**
  - **See increasing reflected solar spectrum toward higher wavenumber in this region. Jun Li of UW-CIMMS is exploring the extraction of information from this region.**

Grating Point Design: Summary of IR Spectral Regions

Spectral Region	Spectral resolution	Number of spectral bins
LW1: 15.4 – 12.54 um	0.0098 um	290
LW2: 12.54 – 10.54 um	0.0065 um	290
LW3: 10.53 – 8.13 um	0.0083 um	290
MW1: 8.44 – 6.78 um	0.0057 um	290
MW2: 7.08 – 5.84 um	0.0043 um	290
SW1: 4.91 – 4.25 um	0.0023 um	290
SW2: 4.32 – 3.80 um	0.0018 um	290

- **The wavenumber (cm^{-1}) resolution requirement was chosen at one point, namely at the shortwave side of the spectral region for each grating.**
  - **LW1 and LW2 started at .625 cm^{-1}; all other IR bands started at 1.25 cm^{-1}**
- **Spectral region coverage is very similar to 3-band ABS coverage, but with improve SWIR resolution.**

Minimal channel set gives good retrieval performance until near surface



(gold LW1SW4)

Wavenumber samples used in second step of retrieval at LL

- **Wavenumber channel, set based on channel set from Dr. Goldberg, give good retrievals down to 800 mb and indicates potential redundancy in spectral coverage. Need to study required number of channels.**

Grating ABS: Multiple slits and overlaps explored

	3-band ABS (to 2720 cm^-1) and 60 um pixels	2-band ABS ("ABS Prime") and 60 um pixels
3 slits, regions have 0.8 um overlap	10 gratings	> 15 gratings (with 2*res in MWIR)
3 slits, regions have 0.5 um overlap	9 gratings	——
3 slits, regions have 0.3 um overlap	8 gratings (full res) 7 gratings (with 2*res from 950-1210cm^{-1}) and 0.5*res in SWIR	15 gratings 8 gratings (with 2*res >1750cm^-1) 7 gratings (with 2*res 950-1210 cm^{-1}, traditional MWIR, and traditional SWIR w/ 2.0*res)
4 slits, regions have 0.8 um overlap	10 gratings	> 15 gratings (with 2*res in MWIR)
4 slits, regions have 0.3 um overlap	7 gratings	8 gratings (with 2*res >1800cm^-1) > 14 gratings (with 1*res in MWIR)

- For full "GIFTS band" coverage, 15 gratings are required which is not possible for any reasonable optical system (8 gratings with reduced MWIR resolution).
- Minimum is 7 gratings, using both traditional side of H_2O and SWIR tweaked by Allen Huang. He anticipates better performance from 7 than 8 grating GIFTS bands. Retrieval modeling is required to fully test 7 grating (first test at night, and then test with solar extraction modeling).

Outline

- Background: wavelength vs. wavenumber
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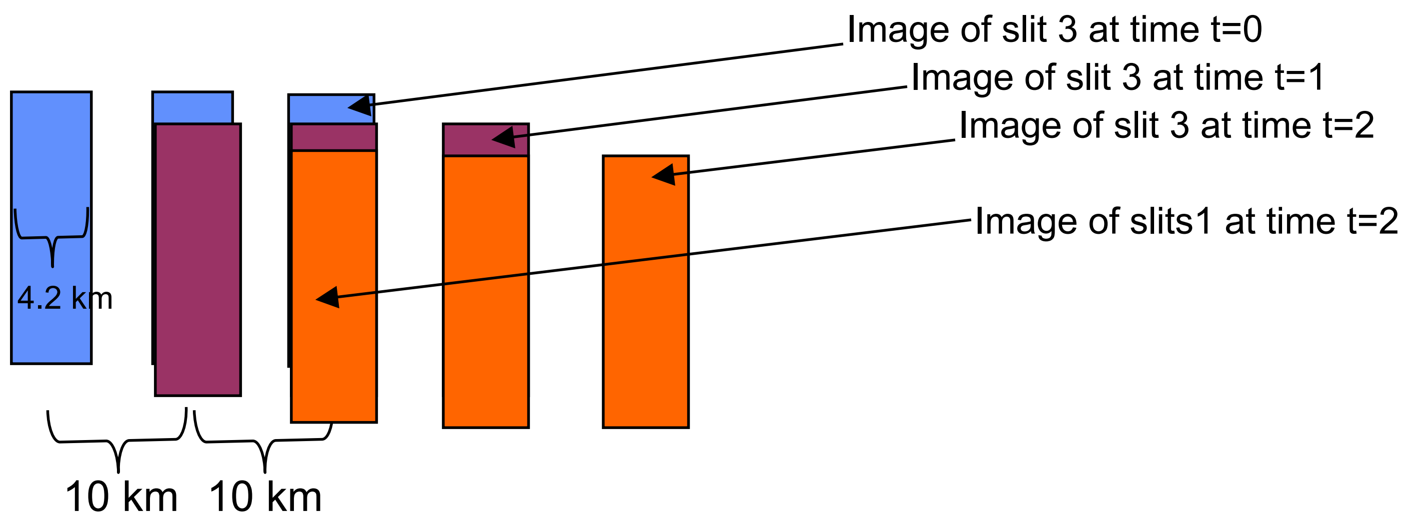
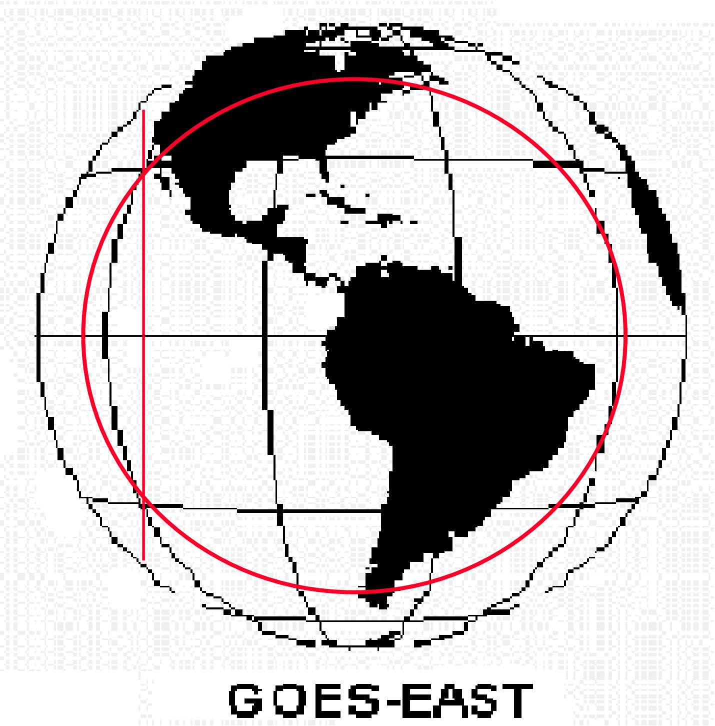
Temporal Design Drivers

- 3 slits imply 3 ground spots that are not co-located.
- Band to band simultaneity requirement is 10 seconds.
- Thus properly spacing the samples permits sample 3 of spectral region 1 to be registered with sample 1 of region 2.
- Because scan plan permits these samples to be well within 1 second of each other, this requirement is met by our grating point design.
- All regions shorter than 10.54 um come from a common slit

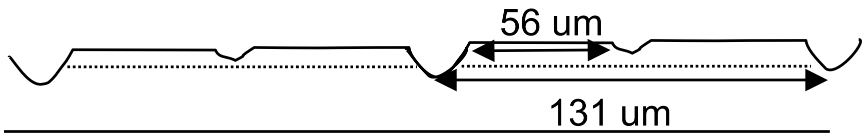


Scan plan

- **Coverage of 62 degree local zenith angle in one hour is required, including time for star looks and calibrations.**
  - **Assuming 1/f performance and detector preamp stability as measured in our laboratory, calibrating the detectors 5 times an hour (~at the end of every other row) is sufficient to minimize 1/f noise.**
  - **Assuming stepping and staring.**
  - **This coverage 11 swaths taking a maximum of 5 minutes.**
  - **Max integration time of 0.21 seconds total for each footprint.**

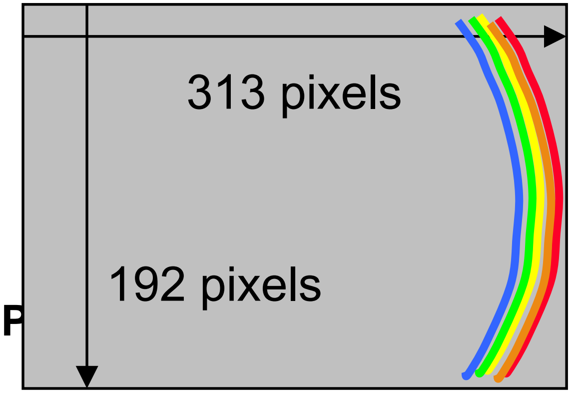


- **FPA detects 96 spatial elements of 10 km**
  - **margin for 10% more field in the telescope.**
  - **two spatial pixels for each 10 km resolution element**



Further implications for FPA

- FPA is (96x2) pixels by 313 pixels covering 96 spatial elements by 290 spectral elements.
  - 10 km covers two spatial pixels
  - Curved image of slit requires extra pixels
  - Equivalent of ~245x~245 array
  - Pixels of 56 um (tall) x 55 um (wide)
  - Implies maximum charge capacity of $1\text{x}10^8$ e^-
  - Newer, small, lower power (4uW/pixel) CTIA F
  - Table of assumed FPA values on next slide



- Multiple reads are employed by several of the FPAs during the maximum integration time of 0.21 sec to avoid saturating the charge storage capacitors.
  - 6 FPA outputs are used to read the 60096 pixels per FPA
  - Multiple outputs reduce rate of each to 0.28Mpix/sec, reducing noise.
  - 6 reads employed in longest (LW1), 4 in next 2 longest (LW2,MW1), 1 in rest (MW2,MW3,SW1,SW2)

Some FPA parameters

	LW1	LW2	LW3	MW1	MW2	SW1	SW2
Wavelength (start)	12.54	10.54	8.13	6.78	5.84	4.25	3.8
Wavelength (end)	15.4	12.54	10.53	8.44	7.08	4.91	4.32
Cutoff Wavelength	15.1	12.54	10.53	8.44	7.08	4.91	4.32
Delta lambda (nm)	9.82	6.54	8.26	5.74	4.26	2.25	1.81
Cd Concentration	20.31%	21.35%	22.48%	24.30%	25.41%	30.31%	32.65%
Donor/Acceptor Con. (1/cm^3)	9.00E+14	1.00E+15	2.00E+15	2.00E+15	2.00E+15	1.00E+14	1.00E+14
Full Scale voltage	1.562	1.859	1.298	0.913	0.6402	0.209	0.0539
ROIC noise (uV)	150*sqrt(readrate)	150*sqrt(readrate)	150*sqrt(readrate)	150*sqrt(readrate)	150*sqrt(readrate)	150*sqrt(readrate)	150*sqrt(readrate)
Readout rate (Mpix/s) per tap; 6 ta	0.286171429	0.190780952	0.190780952	0.047695238	0.047695238	0.047695238	0.047695238
Bias voltage (mV)	-15	-15	-15	-15	-15	-15	-15
Dark current (A)	5.58E-09	2.61E-10	1.57E-11	5.92E-13	2.82E-10	4.51E-15	6.09E-16
RoA	38.9	8.07E+02	1.19E+04	9.74E+05	9.32E+02	6.18E+07	7.52E+08
RA series	1.00E-01	1.00E-03	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
RA shunt	1.50E+03	1.00E+05	1.00E+06	1.00E+06	1.00E+07	1.00E+09	1.00E+09
QE	0.62	0.65	0.68	0.76	0.89	0.96	0.98, 0.97
FPA Operating Temp (K)	65	65	65	65	110	110	110
Estimated Temp of Scene (K)	260	285	270	260	**230**	**270**	**285**
Hottest Scene Temp in Band (K)	314	307	307	306	276	306	306
BB Scene Temp for current interf	289	289	289	267	267	287	287
pixel size (w ith 2 pix/FOV)	55x56	55x56	55x56	55x56	55x56	55x56	55x56
number of elements per FPA (290	313	313	313	313	313	313	313
tint (sec)	0.0350	0.0525	0.0525	0.0525	0.0525	0.0525	0.0525

Summary

- 7 Grating spectral regions have been chosen
  - 7 spectral regions minimize the number of gratings and FPAs subject to manufacturing constraints.
  - Resolution in MWIR and SWIR are degraded over the 2-band ABS system by 2x in the MWIR and SWIR because optical system could not accommodate the number of grating required for the full resolution.
  - 7 spectral regions address the required resolution, originally written for the interferometer. Resolution is always identical or better than 3-band ABS.
  - Improved water vapor performance may be obtainable through employing shortwave coverage, following suggestion from UW-CIMMS---must be fully tested though because working against reflected solar in the daytime.
- Scan plan meets requirements
  - Coverage rate (62 degree local zenith angle in one hour)
  - Band to Band simultaneity (10 sec)
  - Swath to Swath simultaneity (6 minutes)
- FPAs are result of constraints on current FPA manufacturing, and instrument coverage rate, optical field, and signal limitations
  - 96 spatial x 290 spectral (192x313pixels), 56umx 55 um pixels, 6 outputs

Radiometric Performance Modeling

Jane Luu

BASIC GRATING FEATURES

- Slit length (N-S direction) defined by field of view
- Slit width (E-W direction) set by spectral resolution
- Focal plane array (~ 300 x ~ 200)
- Current pixel size: 10 km x 4 km

SIGNAL

Current [A] : $$I_{ph}(\lambda) = L(\lambda)\, \tau \frac{\lambda}{hc} \eta\, q\, A_{det} \Omega_{opt}\, \Delta\lambda$$

electrons [e $^-$]: $$N_{e-} = \frac{I_{ph}\, t_{int}}{q}$$

$L(\lambda)$ = scene radiance [Wm^{-2} sr^{-1} μm^{-1}]

τ = optical transmission

η = quantum efficiency

A_{det} = detector area [m^2]

Ω_{opt} = optics solid angle [sr]

t_{int} = integration time [sec]

$$\Rightarrow \boxed{N_{e-} \propto \underbrace{L(\lambda)\, \tau\, \eta\, A_{det} \Omega_{opt}\, \Delta\lambda}_{\text{flux falling on each pixel}} \bullet t_{int}}$$

NOISE

- Shot noise: signal, background, dark current
  - $\Rightarrow$ rms noise current:

$$i_n = \sqrt{2\,q\,I\,\Delta f} \qquad \text{[A]}$$

$$\begin{array}{lll} q = & \text{electron charge} & \text{[C]} \\ I = & \text{mean current} & \text{[A]} \\ \Delta f = & \text{noise bandwidth} & [\text{Hz}^{-1}] \end{array}$$

- 1/f noise
- Readout noise ($\propto$ readout rate per output)
- Quantization noise
  - 12 bit A/D conversion

FIGURES OF MERIT

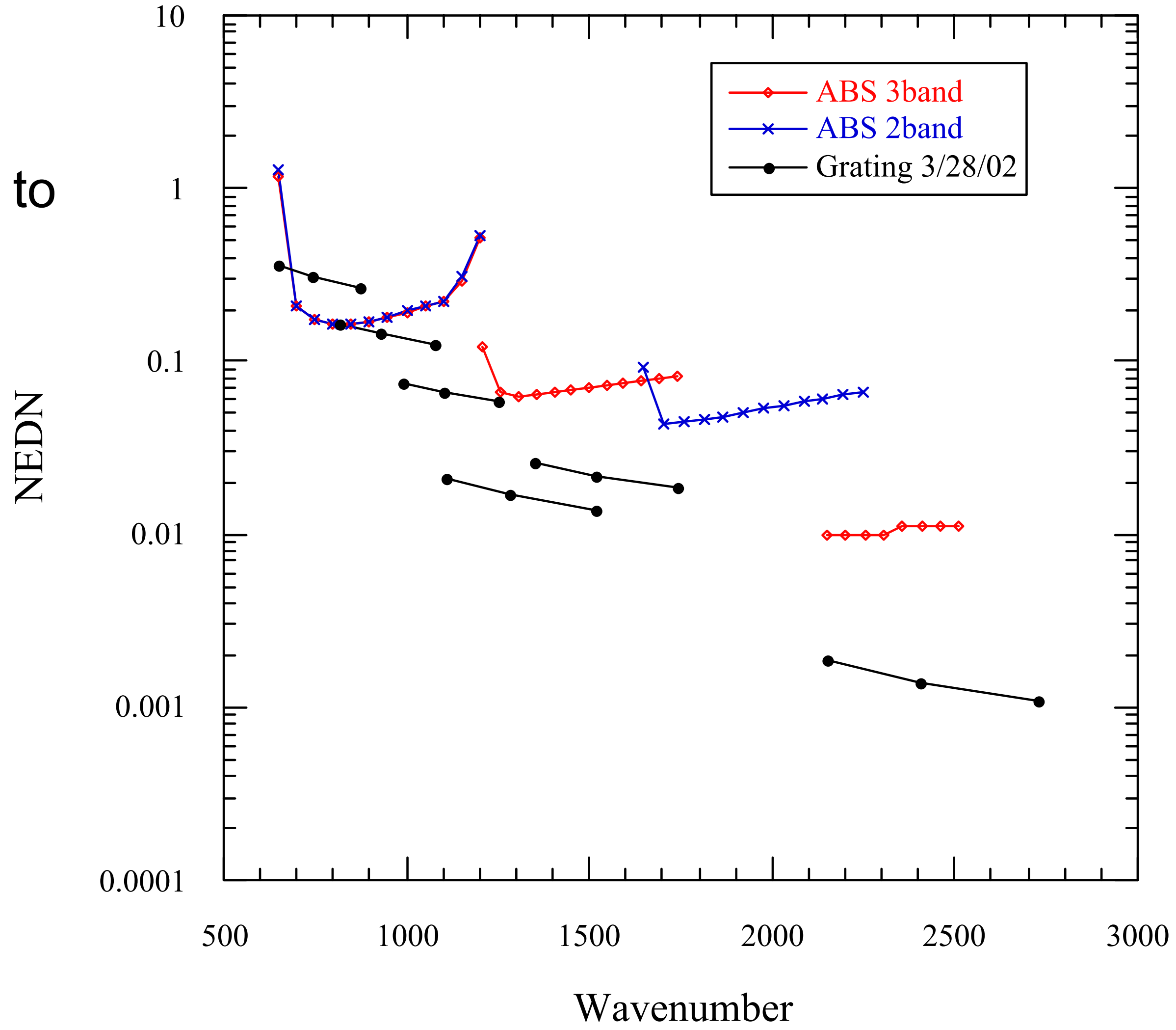
- S/N (signal-to-noise ratio)
- NEDT (noise equivalent temperature) [K]
- NEDN (noise equivalent radiance) [mW m^{-2} sr^{-1} $(cm^{-1})^{-1}$]

GRATING DESIGN HISTORY

	Date	D_{tel}	No. slits	No. gratings	Volume
	1/08	0.30m	1	7	
	1/31	0.30m	1	6	
	2/12	0.30m	1	3	63" x 35" x 12"
	2/14	0.30m	1	4	60" x 33" x 12"
	2/22	0.30m	1	8	64" x 33" x 12"
	2/25	0.30m	1	6	
⇒	3/27	0.30m	1	5	44" x 31" x 12"
	4/11	0.30m	1	5	increase FOV
	4/25	0.35m	3	8	
	4/30	0.35m	4	9	
	4/30	0.35m	3	9	
	5/06	0.35m	3	8/9	
	5/10	0.35m	3	7	
	5/23	0.30cm	3	7	58” x 35” x 12”

GRATING DESIGN 3/28/02

- 1 slit
- 6 gratings
- Detectors cooled to 65K (SW) and 110K (LW)



NB: QE assumed constant across band

INCREASING SNR

- Minimize noise
  - shot noise: signal, background, dark current
  - 1/f noise
  - readout noise
  - quantization noise

- Maximize signal
  - since $N_{e-} \propto L(\lambda)\,\tau\,\eta\,A_{det}\Omega_{opt}\,\Delta\lambda\,t_{int}$,

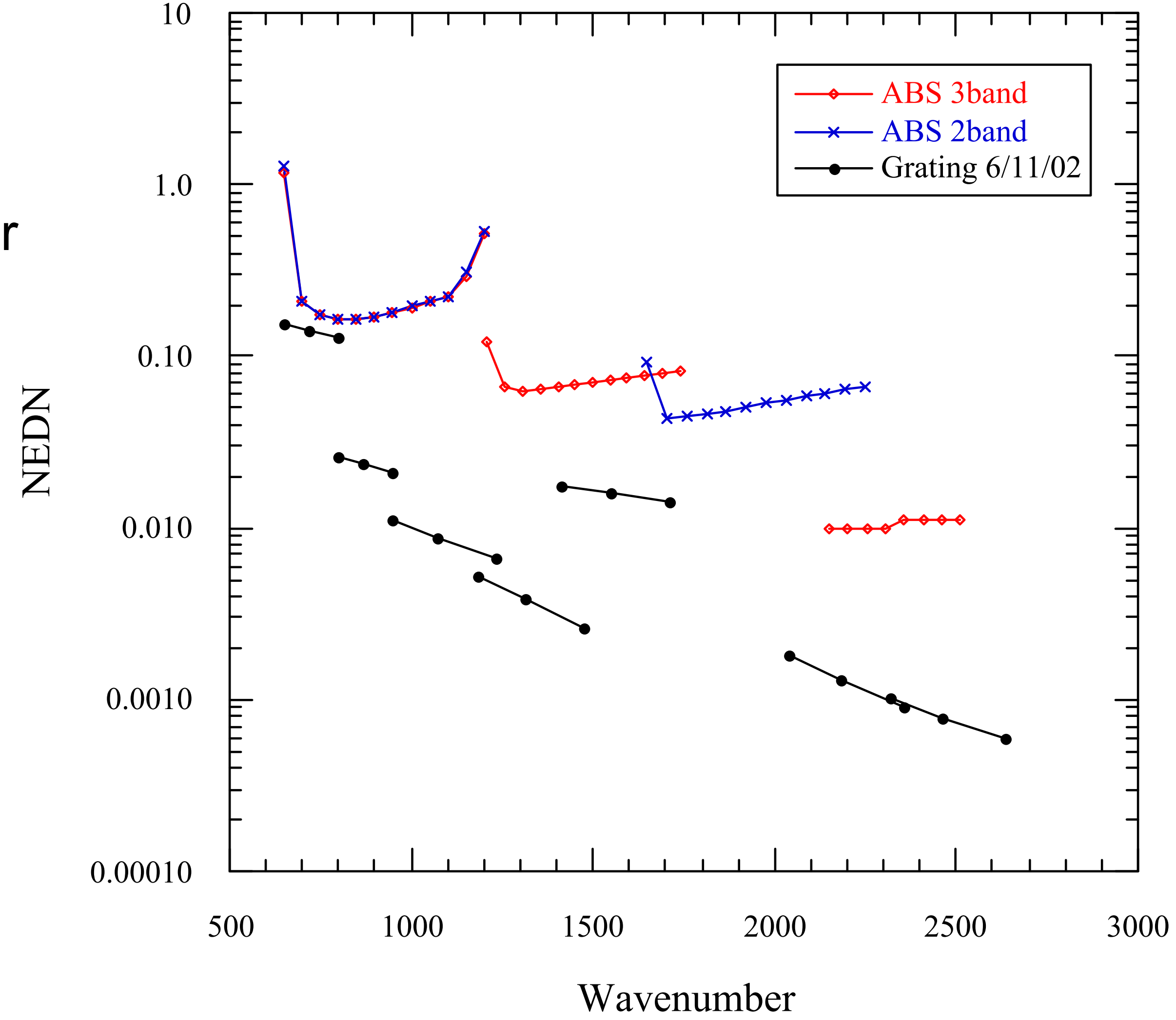
  can maximize τ , A_{det}, Ω_{opt} , t_{int}

GRATING DESIGN 6/11/02

- 3 slits
- 7 gratings

- 313 x 192 pixels per channel

- Detectors cooled to 110K (SW) and 65K (LW)



NB: QE assumed constant across band

GRATING CHALLENGES

1) Small field of view: 10 km x 4 km (due to narrow slit)
2) Short integration time: 0.21 sec (due to coverage requirement)

- $SNR \propto \sqrt{t_{int} A_{det} \Omega_{opt}}$

- Interferometer much less affected by these problems
  - Field of view: 10 km x 10 km
  - Integration time: more than 10x larger

GRATING VS. INTERFEROMETER

- When might grating be preferrable?
  - Lower spectral resolution
  - Narrower spectral coverage
  - Relaxed coverage rate

SUMMARY

- Grating design meets performance requirements

- SNRs limited by
  - (small) field of view
  - (short) integration time

- Current design: 3 slits, 7 gratings
  - meets specs in all bands by factor of > 5 except in longest band
  - little margin at longest band (20%)

Advanced Baseline Sounder Optical System

Danette Ryan-Howard

GOES Quarterly Review Meeting
Lexington, MA
20 June 2002

Outline

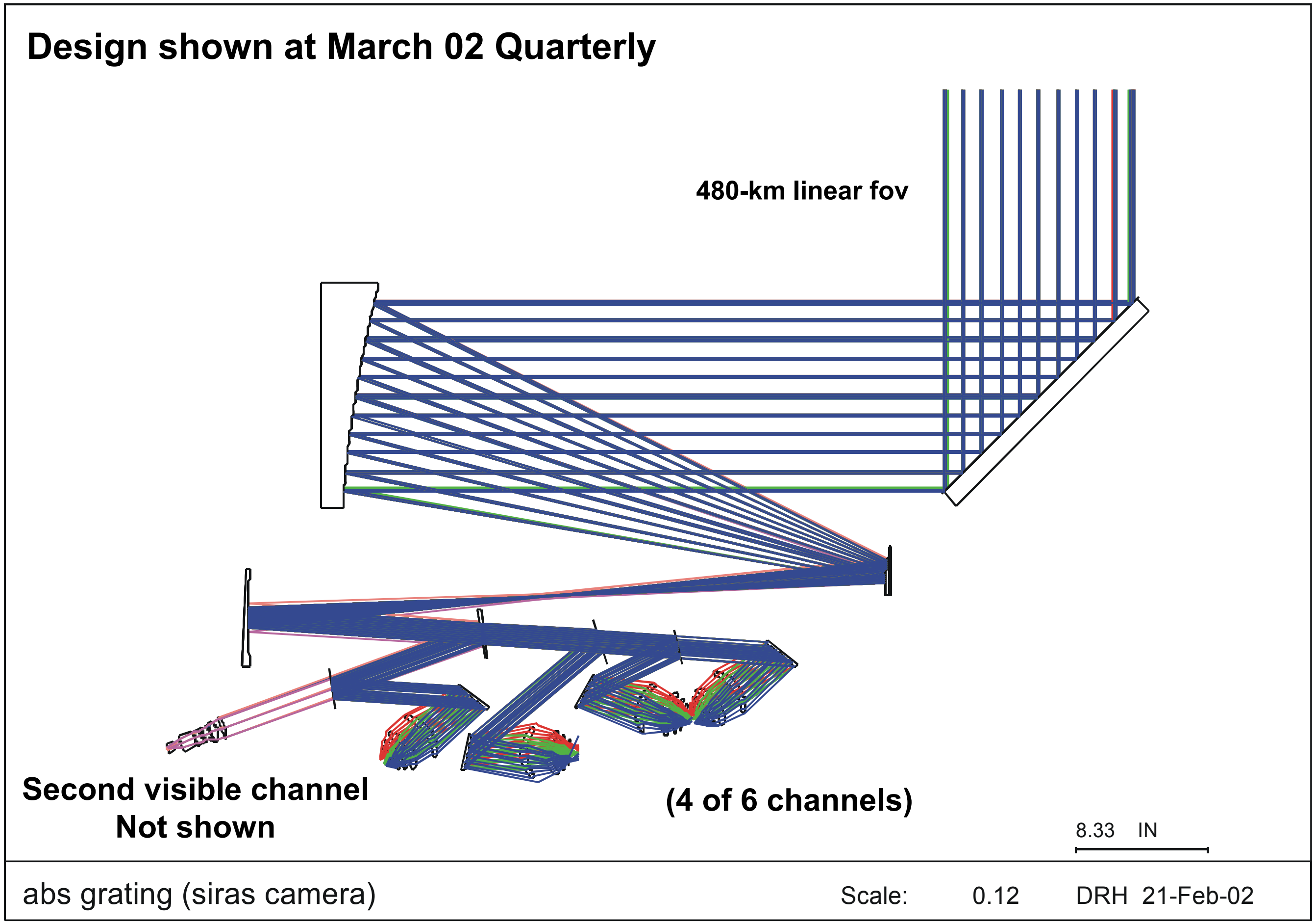
- Basic Requirements.
- Design History.
- Changes and Iterations.
- Current Strawman Design.
  - 7 Infrared Channels
  - Multiple Slits.
- Grating and Field-of-View.
- Summary

Basic Requirements

- 12-inch aperture telescope.
- 10-km infrared spatial resolution.
- Grating(s) located at image of aperture stop.
- Linear field-of-view.
- Accessible field image for slit.
- Spectral resolution requirement defines maximum slit width.
  - Slit may map to less than 10-km width on ground.
- Large field-of-view to maximize integration time.
- 2 visible channels (cloud sensing and low-light imaging).

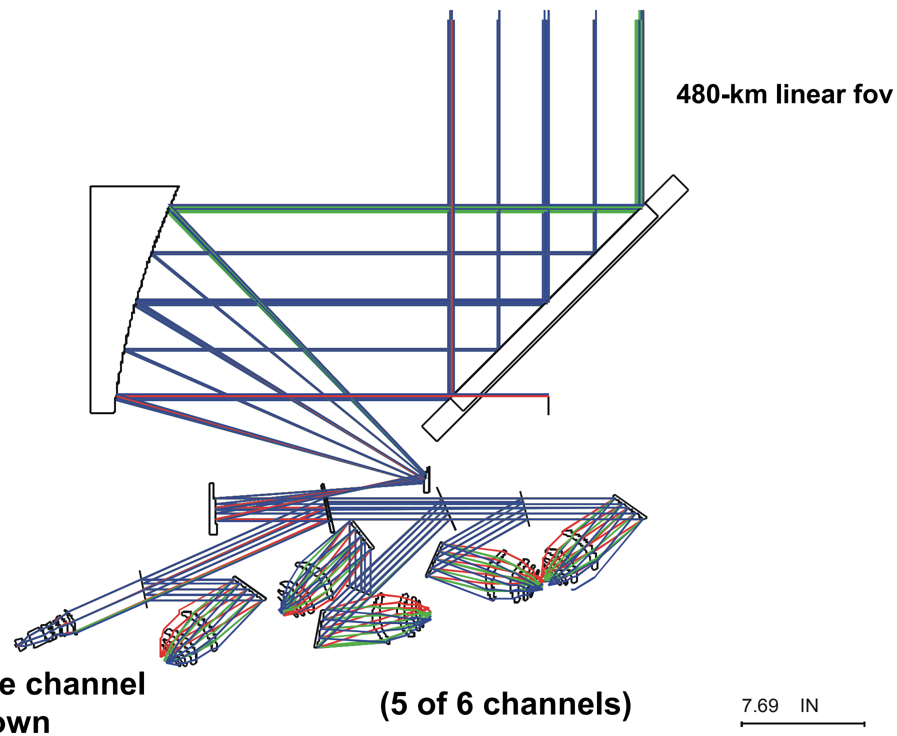
Strawman Grating Design (March 02)

Design shown at March 02 Quarterly



Strawman Grating Design (March 02)

Revised design employing smaller telescope



absgrating linear FOV 480km vis channel

DRH 12-Mar-02

Changes and Iterations

- System had insufficient signal
  - Add additional slits to avoid dichroic losses in longwave bands
    - Relay optics required
  - Double FOV to allow increase in integration time
  - Increase pixel width to allow larger slit width (2 km to 4-5 km GFOV)
  - Increase aperture diameter (12” to 14”)
  - Relax volume constraints to accommodate changes
- Adjust band edges
  - Maintain Spectral Resolution
  - Adjust spectral overlap
  - Maximum width of FPA constrains design space
- Adequate signal gains allowed return to 12” aperture diameter
  - Multiple Slits (width maps to 4.2 km GFOV)
  - Spatial field-of-view = 960 km
  - 7 Infrared Channels
  - Two visible channels

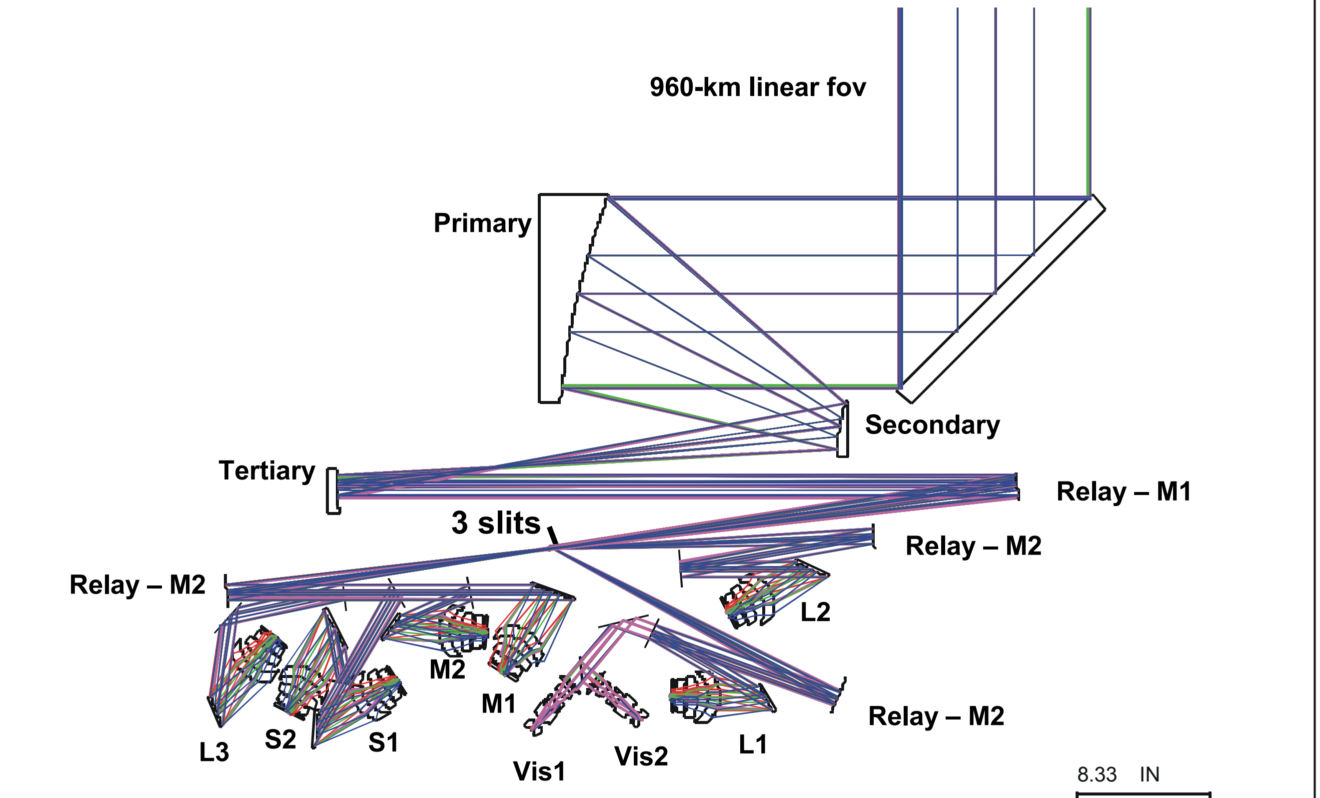
Current Strawman Design

Design Wavebands and Resolutions

Channel	L1	L2	L3	M1	M2	S1	S2	Vis1	Vis2
Low λ *	12.54	12.54	10.53	6.78	7.08	4.91	4.32	0.5	0.5
High λ	15.40	10.54	8.13	8.44	5.84	4.25	3.80	0.7	0.7
λ Resolution	.0098	.0065	.0083	.0057	.0043	.0023	.0018	low cloud	

* All λ in μm.

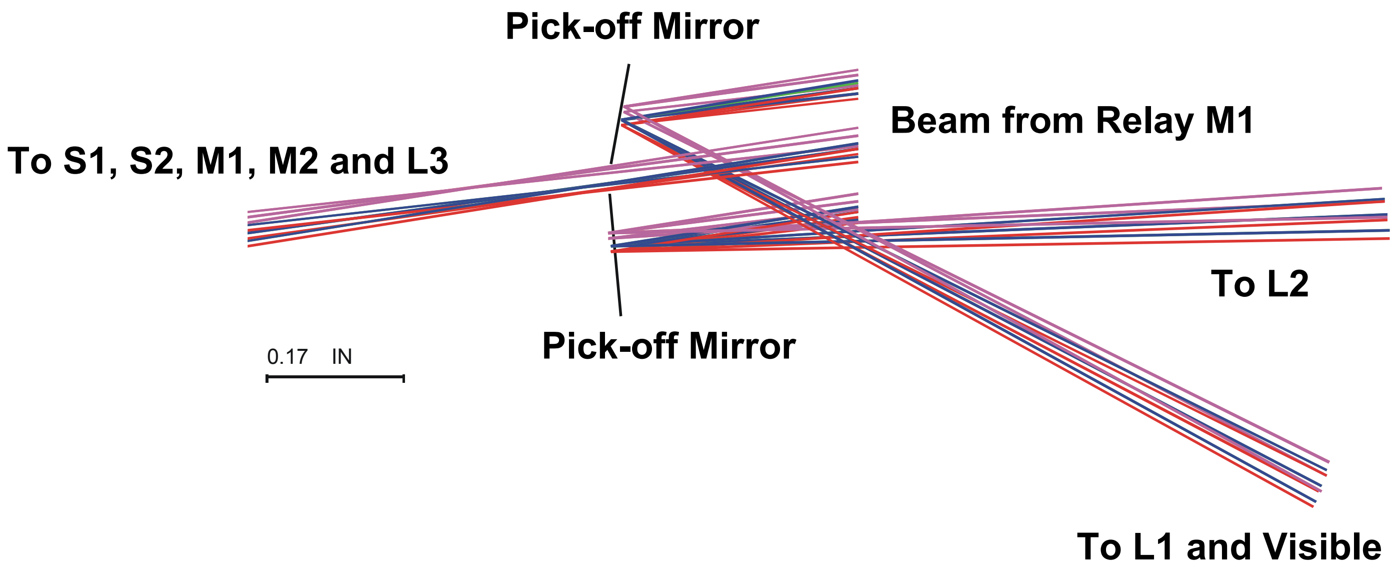
Strawman Grating Design (7 Channels)



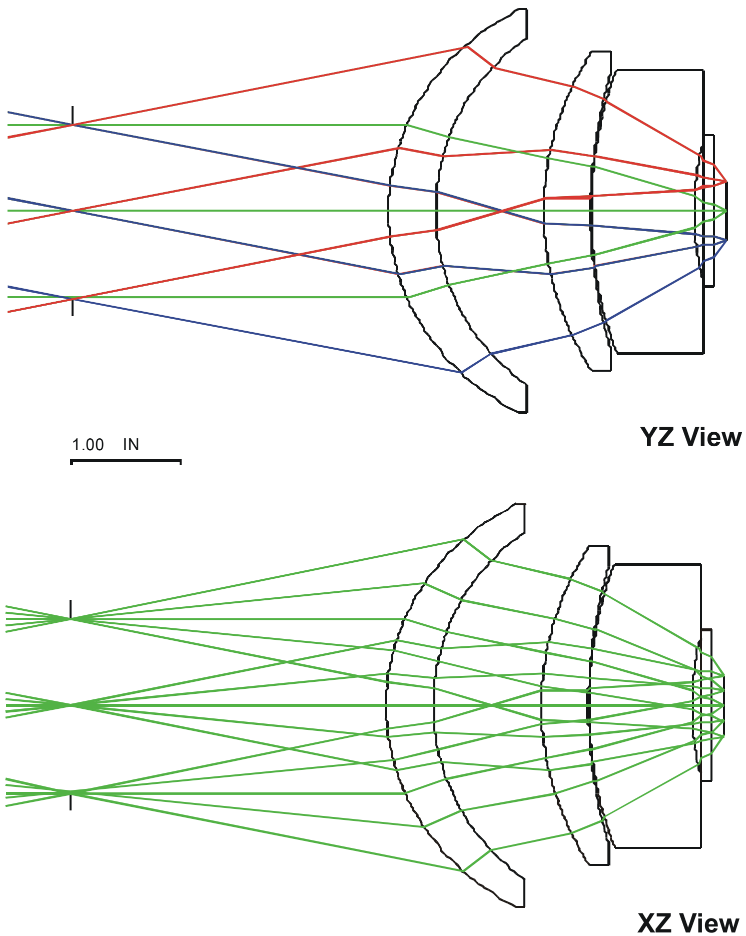
Volume (optics only) = 58" x 36" x 12" = 1.45 m x .9 m x .3 m

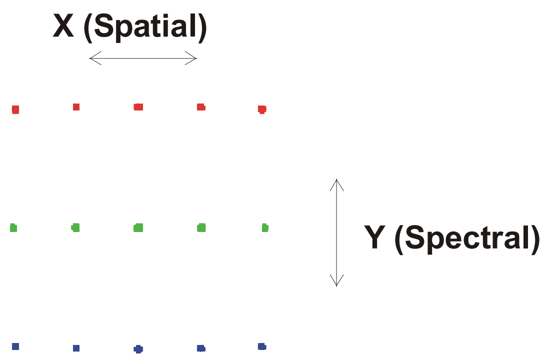
DRH 12-Jun-02

Slit Plane in Relay Optics

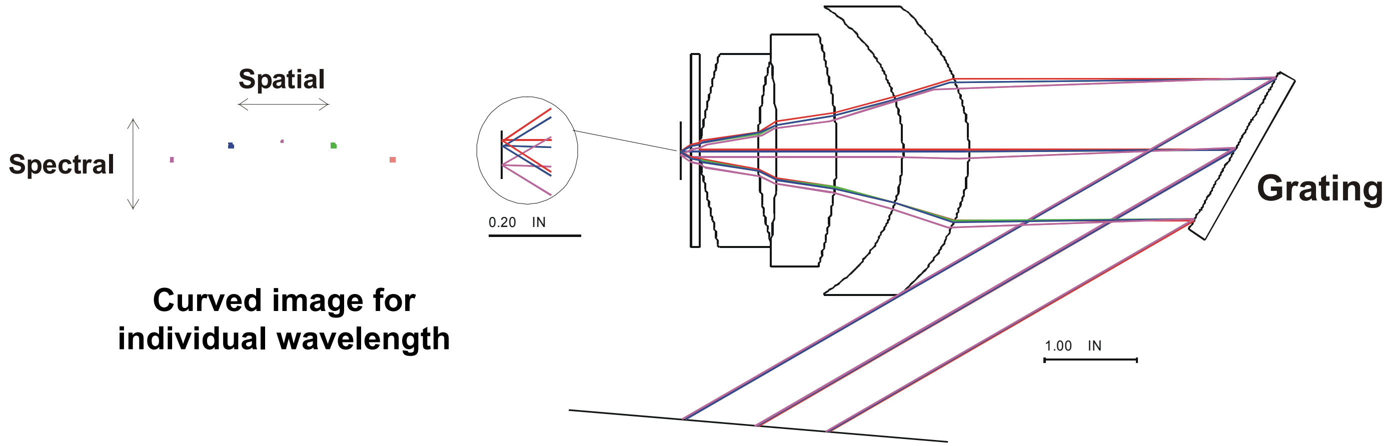


Infrared Imaging Lenses

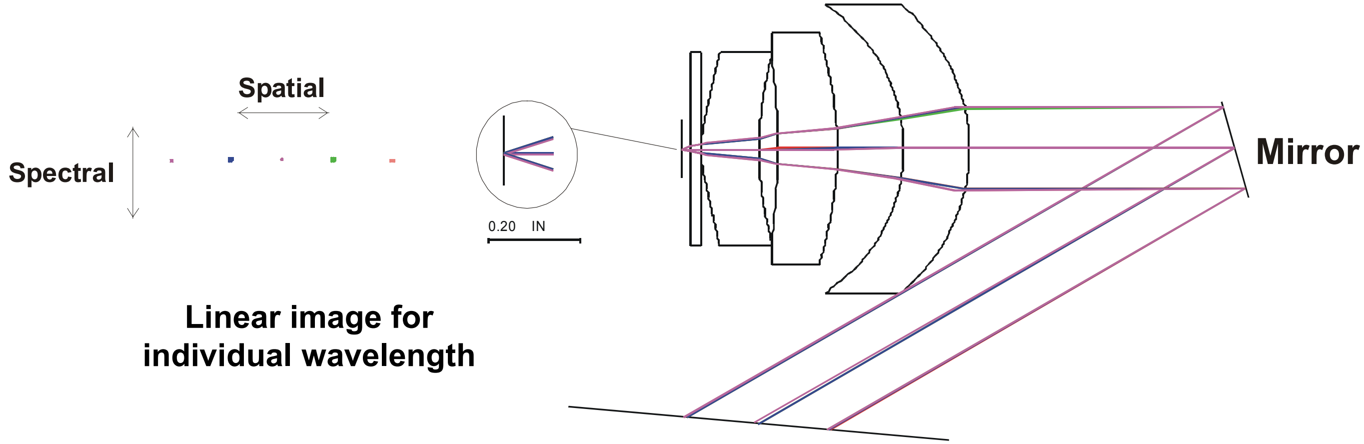




Grating with Large FOV



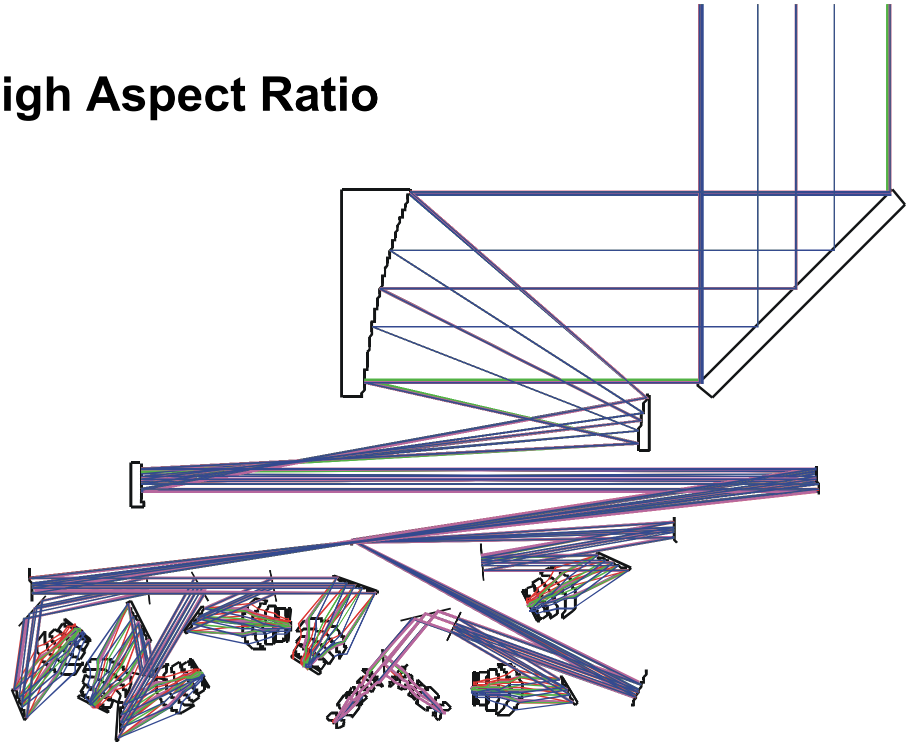
Curved image for individual wavelength



Linear image for individual wavelength

Summary

- **Strawman Design Meets Performance Requirements**
- **Complex Design**
  - **7 Infrared Channels**
  - **2 Visible Channels**
  - **Multiple Slits with High Aspect Ratio**
  - **Large Volume**



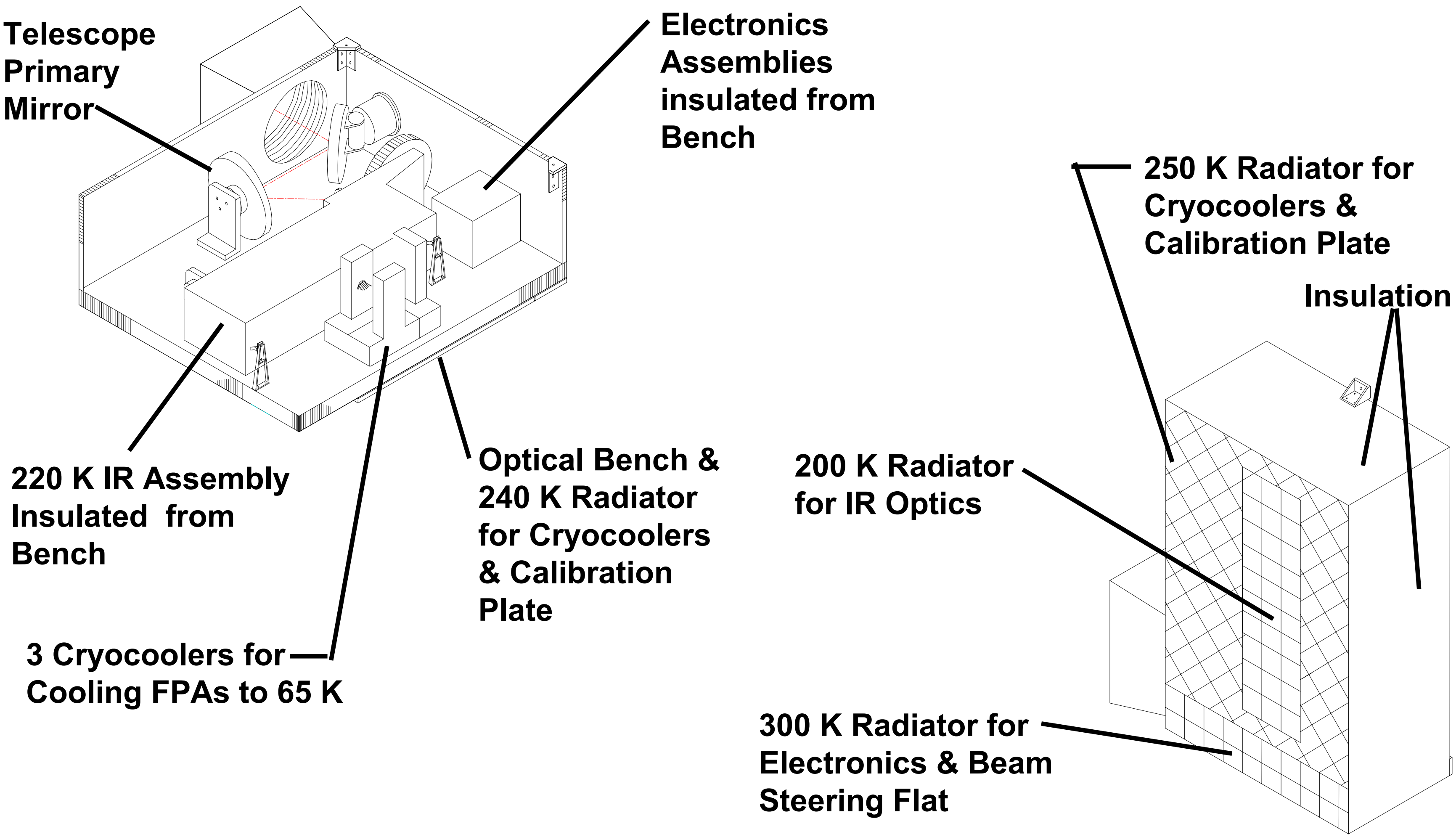
THERMAL & MECHANICAL SYSTEM

Darryl Weidler
20 June 2002

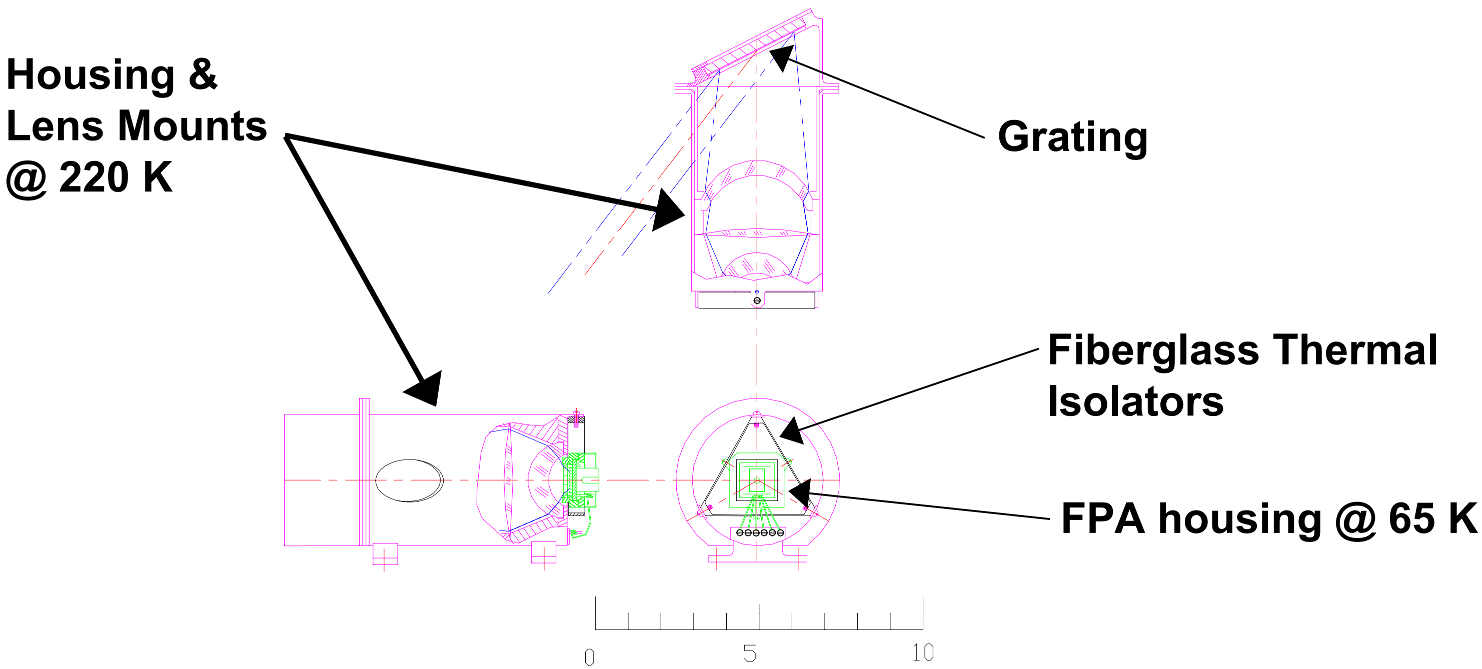
THERMAL & MECHANICAL OUTLINE

- Mechanical & Thermal Concept
- Focal Plane & Grating Assembly
- 220K Optics Assembly
- Configurations Considered
- Cryocooler Usage
- Thermal Radiators
- Weight Estimate
- Summary

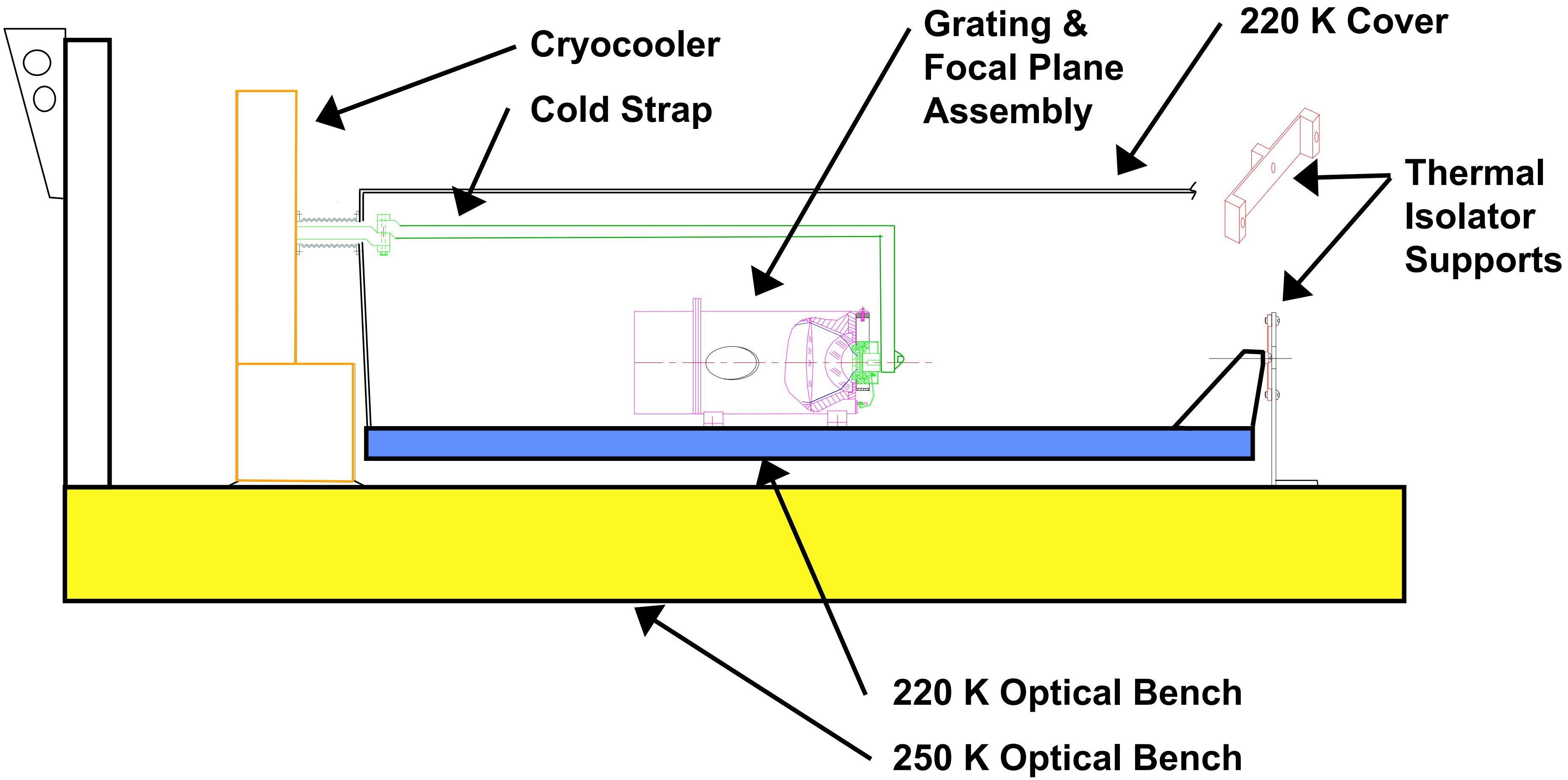
Mechanical & Thermal Concept



Focal Plane & Grating Assemblies

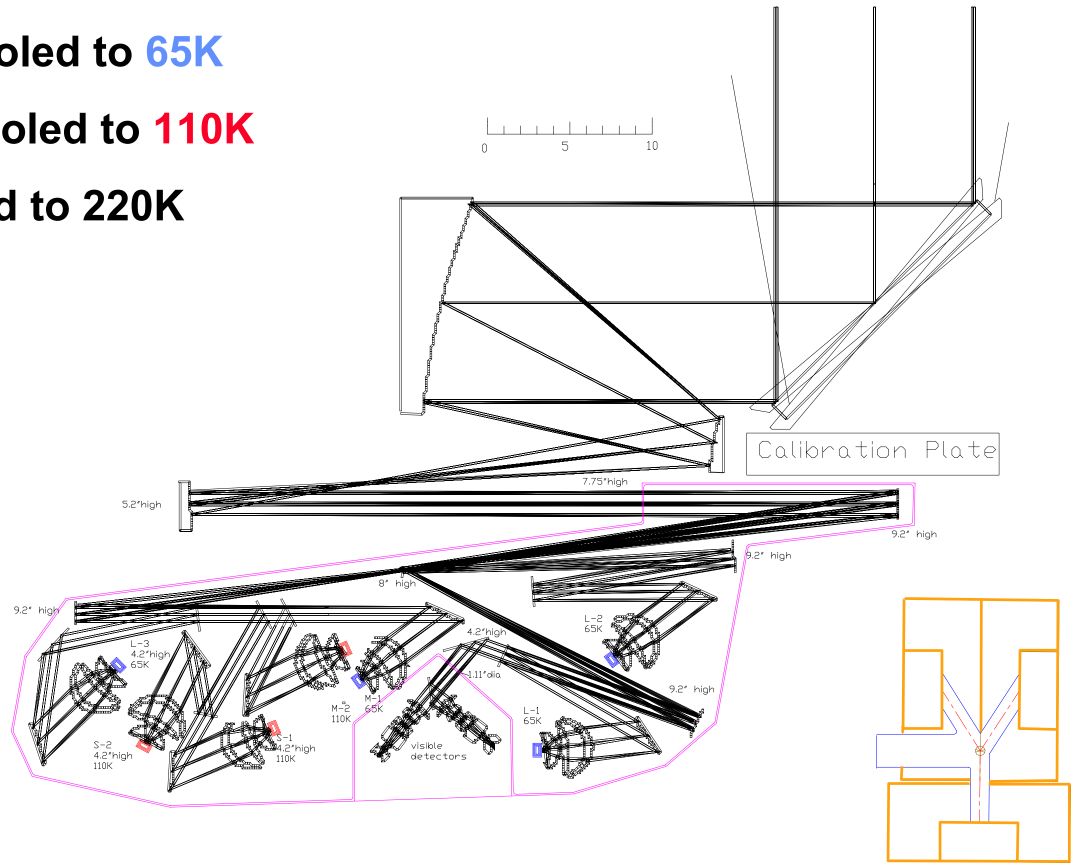


220K Optics Assembly Concept



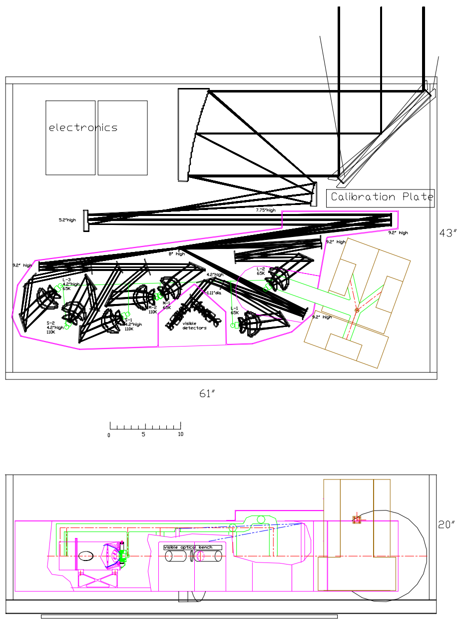
Focal Plane Arrays to be Cooled

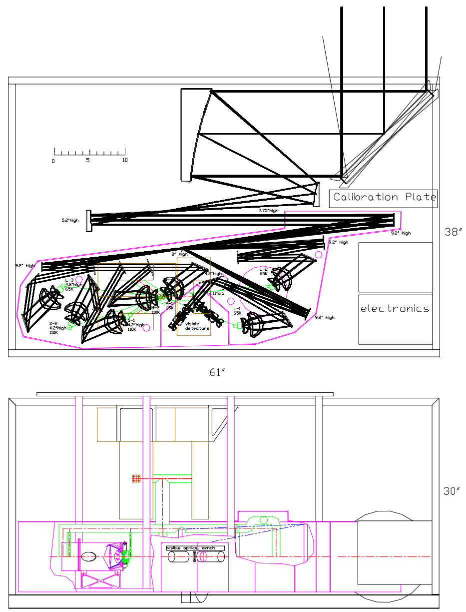
- Long wave detectors cooled to 65K
- Short wave detectors cooled to 110K
- Optics within Box cooled to 220K

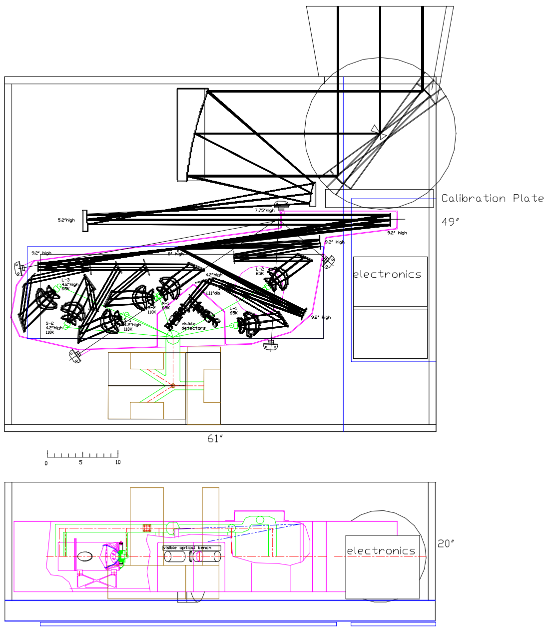


•Three cryocoolers connected at cold areas to cool FPAs

Configurations Considered







- Smallest Package Size
- Requires 3 cryocoolers
- Long 65K Thermal Path

- Requires 2 cryocoolers
- Must mount to radiator
- Radiator above bench
- Long thermal path to radiators

- Requires 2 cryocoolers
- Everything mounts from the optical bench
- Bench becomes radiator
- Chosen for this study

Cryocooler Heat Load & Operation

Heat Source	Heat Input (W) 65K FPAs	110K FPAs
Radiation to Housing	.068	.063
Insulators	.095	.065
Conduction Thru Wires	.078	.052
FPA Power Dissipation	.255	.240
Radiation to Cold Straps	.148	.020
Total Per FPA Assembly	.644	.440
Number of FPA Assemblies	x 4	x 3
	2.576	1.320
Total For FPAs	3.896	
Cryocooler Cold Straps	.250	
Non-Operating Cryocooler	.800	
Total 65K Heat Load	4.946	

- 2 Cryocoolers Operating @ 99% of Full Capacity
  - 1 Spare Cryocooler
- 3 Cryocoolers Operating @ 55% of Full Capacity
  - No Spare

Note power numbers reflect 7 FPAs here

Passive Thermal Radiators

Heat Inputs	200K Radiator (W)
Radiation	17.5
Solar Array	4.3
Heat to 65K Components	-2.2
A/Ds	1.8
From 250K Radiator	1.0
	22.4

Heat Inputs	250K Radiator (W)
Calibration Plate	7
Solar Array	14
Cryocoolers	150
Heat to 200K Radiator	-1
	170

Heat Inputs	300K Radiator (W)
Scan Mirror	20
Solar Array	1
Electronics	30
Conduction From S/C	5
Total	56

Area Required: 0.31m^2

Assume .33m x .94m

Area Required: 1.17m^2
(must include 200K radiator)

Assume l.24m x 1.19m

Area Required: 0.16m^2

Assume .3m x .53

Total Area of Radiators = 1.64 m^2; Sensor N/S Radiator Area =1.82 m^2

Note power numbers reflect 7 FPAs here

Mass Estimate

Sensor	Mass, Kg	Comments
Telescope Optics	10.4	50% LW, Primary mirror
Visible Assembly	2.6	
IR Assembly @ 220K & 65K	36.6	Including 65K cold straps and FPA's
Turning Flat & Drive	13.2	Si-C 50% lightweighting
Housing	51.1	Housing and calibration plate
Radiators	4.4	
Baffles external & internal	9.1	
Cryocooler Assembly	14.7	3 cryocoolers, 65K cold straps and housing
Input aperture cover	5.5	
Shielding (rad. & mag.)	1.0	
Thermal Control	3.4	Assume 2%
Electronics	20.0	2 @ 10.0 Kg each
Cabling	2.0	
Sensor subtotal	**174.0**	
Contingency 20%	**34.0**	
Sensor Total	**208.0**	

Note power number reflect 7 FPAs

Summary

- Large Plan-View Suggests Optical Bench Approach
- 5 Watts Cooling @ 65 K
- Adequate Area for Thermal Radiators
- Thermal Management Challenge
- No Technical “Show Stoppers” at This Time

ABS Grating Design Summary

David Weitz

GOES Quarterly Review

20 June 2002

Grating and FTS Instrument Comparison

	FTS	Grating
Mass	185 kg	208 kg
Power	235 W	215 W
Volume	1 m^3	155x125x51 cm
Data Rate	10 Mbps	15 (16 max.) Mbps

Note grating system power numbers not yet updated for 5 FPAs

Grating and FTS Instrument Comparison

- Many more detectors for grating design, but simpler signal processing electronics
- Aggressive optical and thermal/mechanical design for grating design
- Present grating point design is cumbersome; a more elegant solution might exist
- Risks associated with grating instrument would likely be comparable in degree to FTS instrument risks

Potential Follow-up Work

- Present ABS grating point design flows down from existing instrument performance requirements, which are justified by sounding retrieval studies
  - These studies implicitly assume an FTS instrument
- Substantial simplifications might be possible if science team can demonstrate adequate performance using, say, fewer spectral bands and/or reduced spectral resolution
- MIT/LL will further investigate these ideas

ABS Grating Design Update

David Weitz

GOES Quarterly Review

22-24 October 2002

Outline

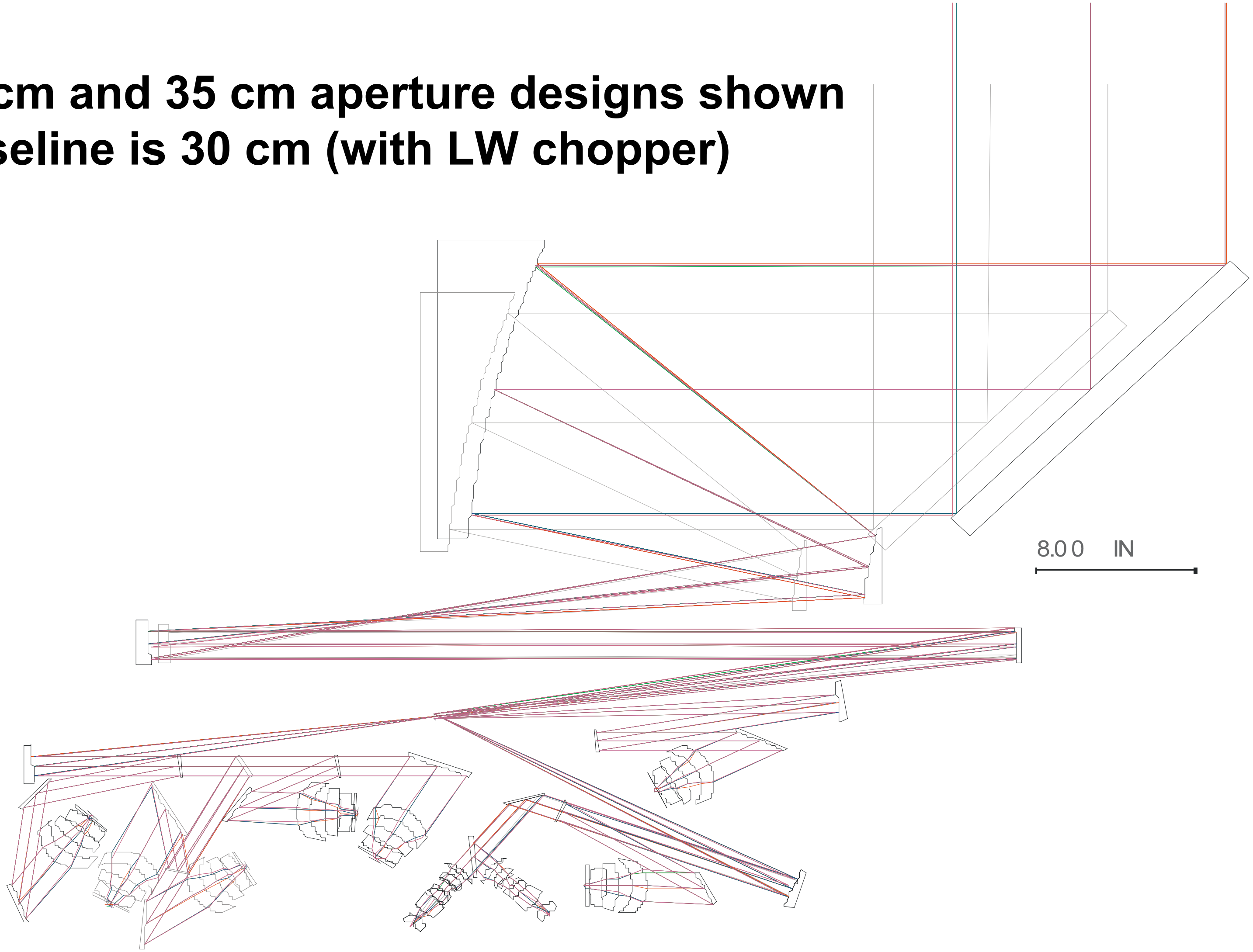
- Optical design status
- Mechanical/Thermal system status
- FPA format changes
- Mechanical chopper in longest-wave band
- Pointing mirror motion

- Team: Blackwell, Coakley, Luu, Ryan-Howard, Weidler, Weitz

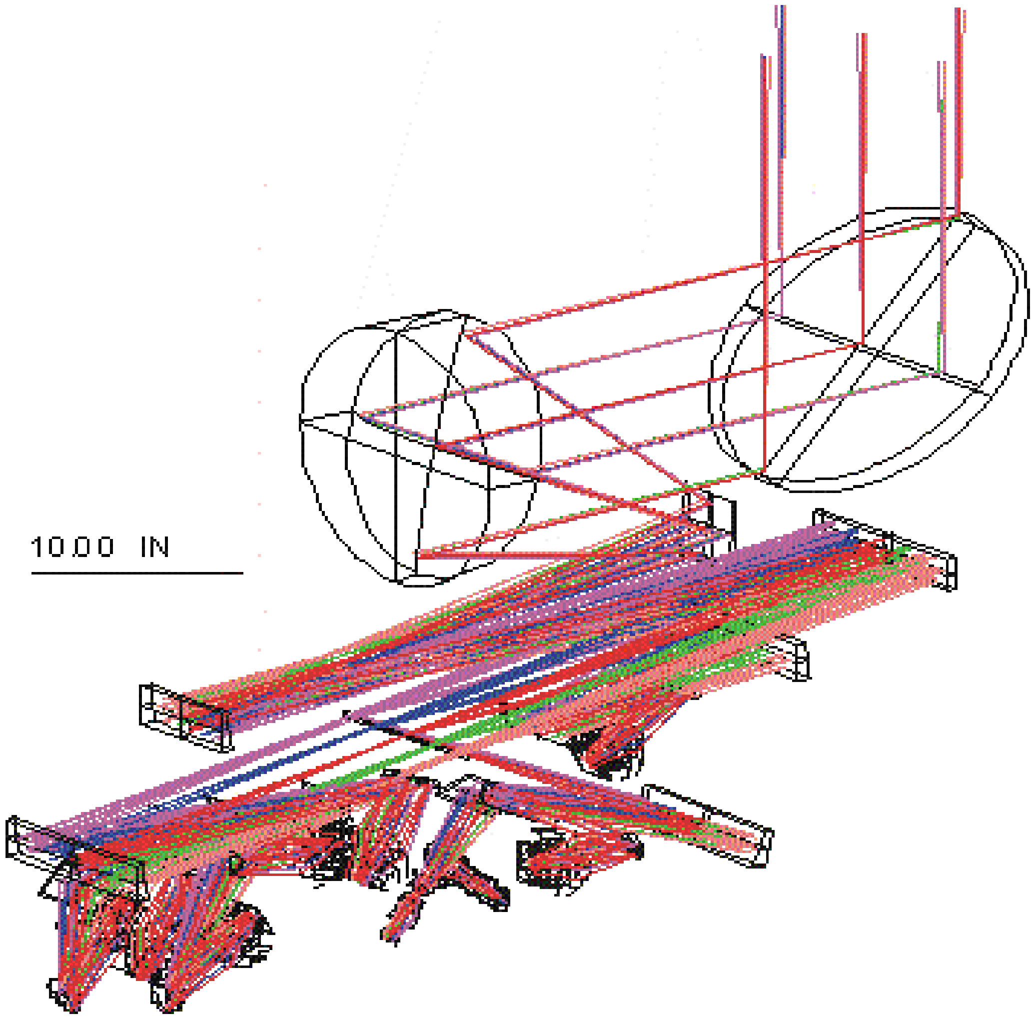
- N.B.: this point-design based on ABS TRD released July 2002

ABS Grating Baseline Optical Design

- 30 cm and 35 cm aperture designs shown
- Baseline is 30 cm (with LW chopper)

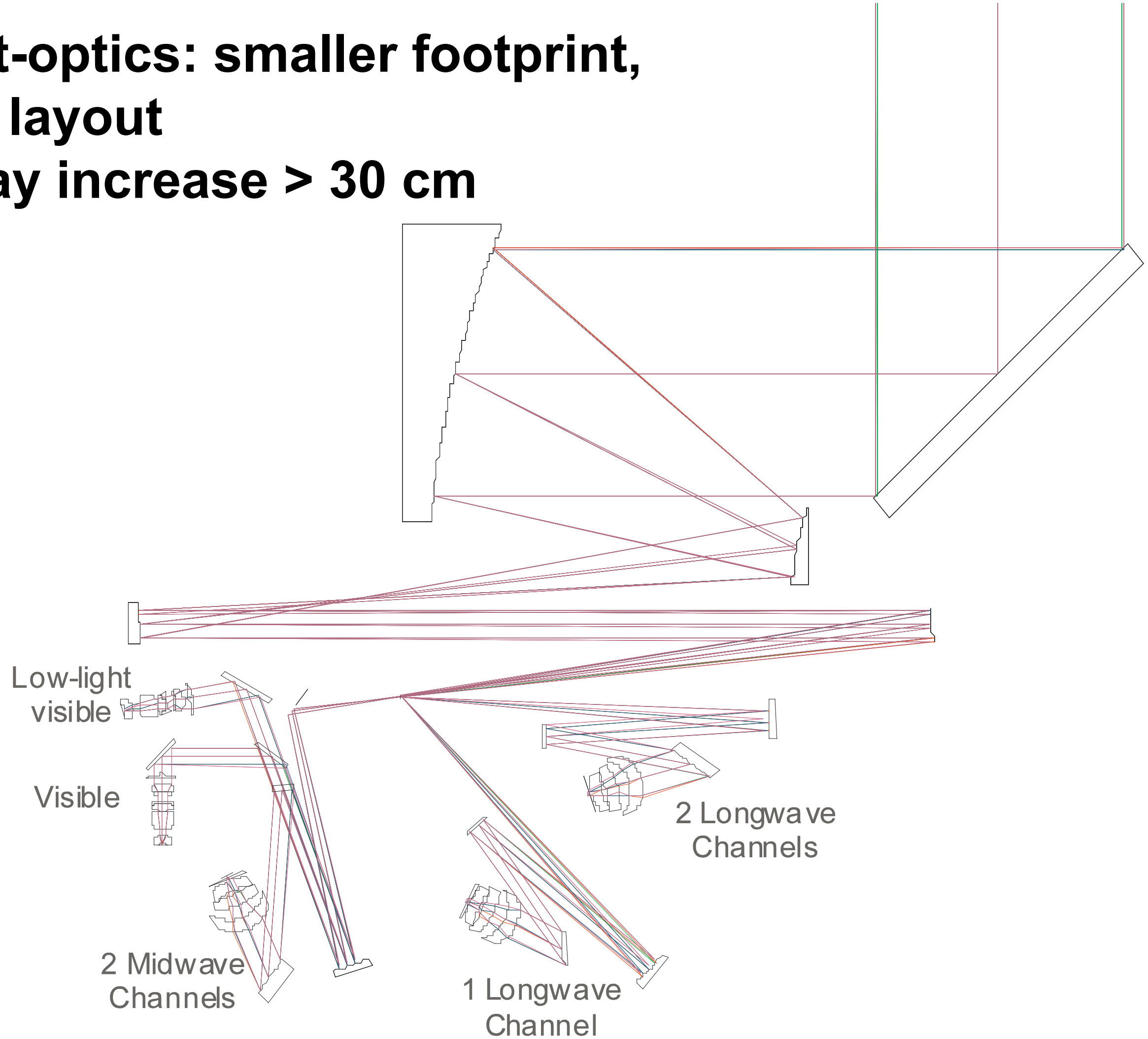


ABS Grating Optical Design (3d view)

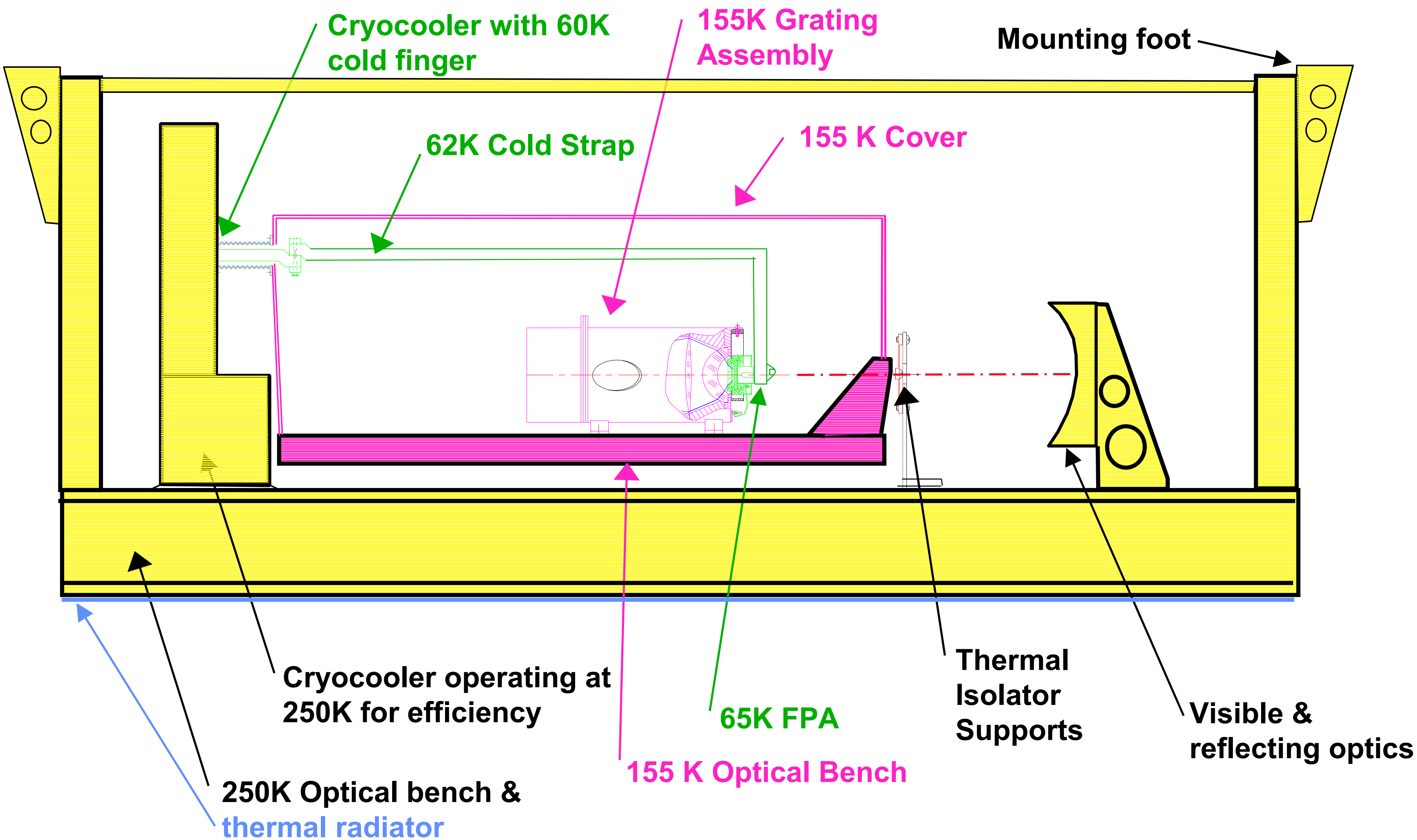


ABS Optical Design Alternative

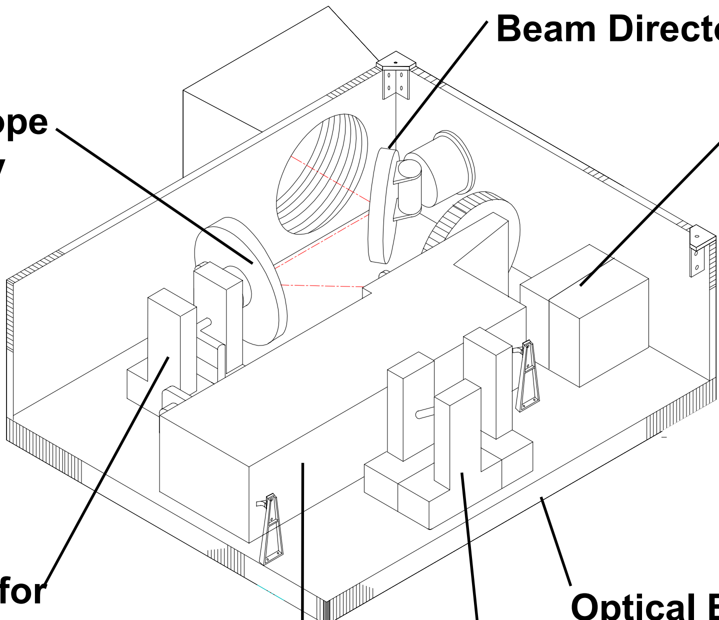
- "Axicon" aft-optics: smaller footprint, more flexible layout
- Aperture may increase > 30 cm

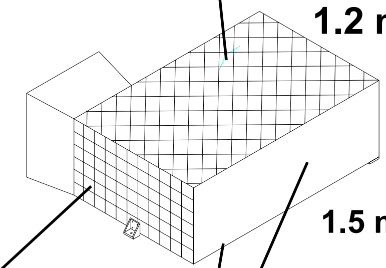


Mechanical & Thermal Concept

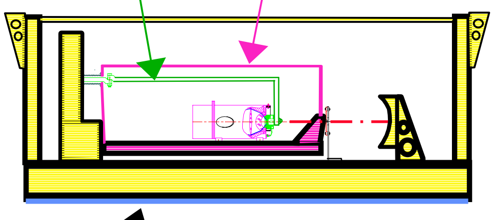


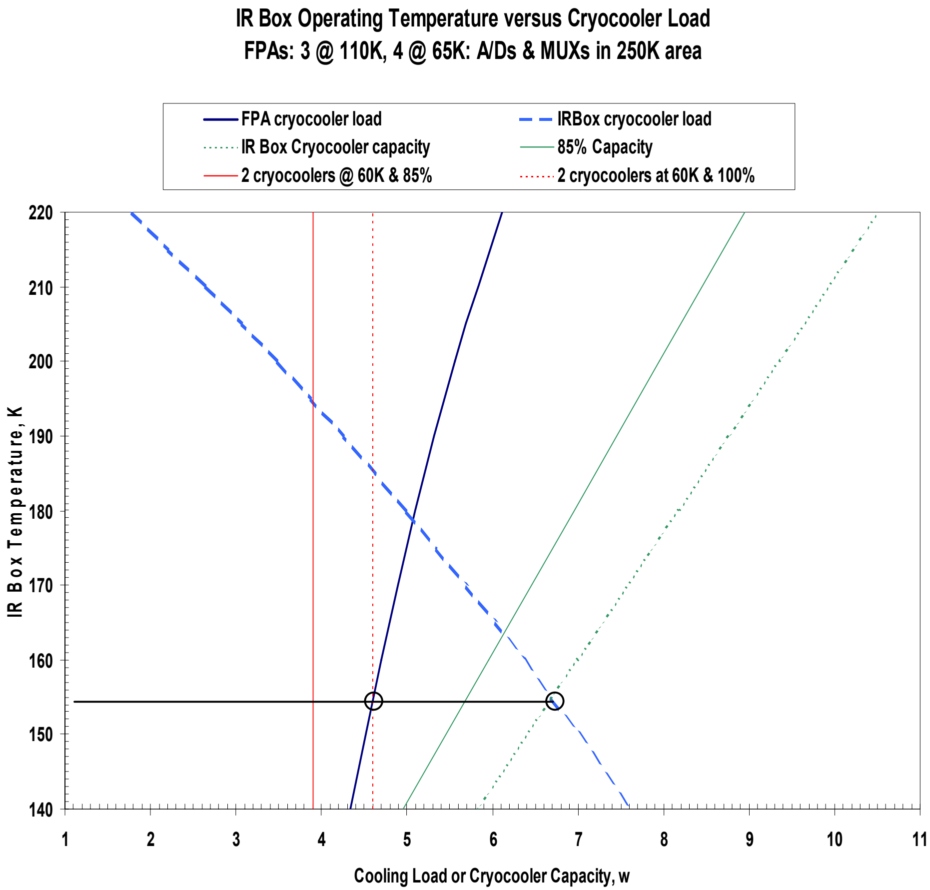
Mechanical & Thermal Configuration



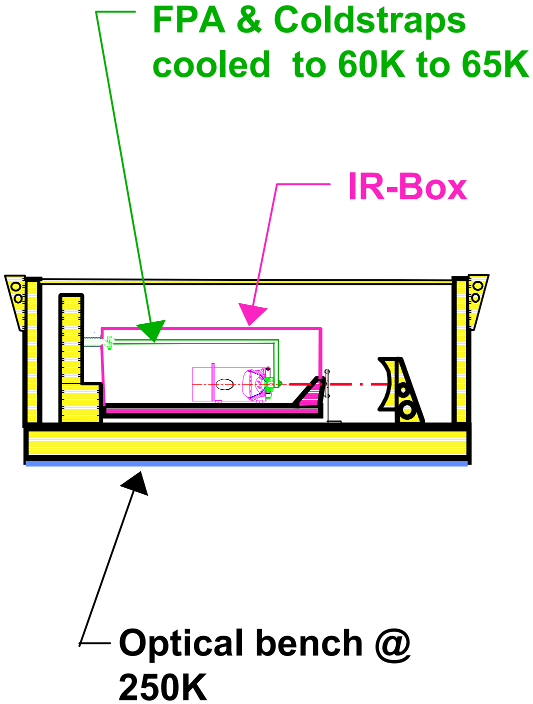


Operating Temperatures for 7 FPAs

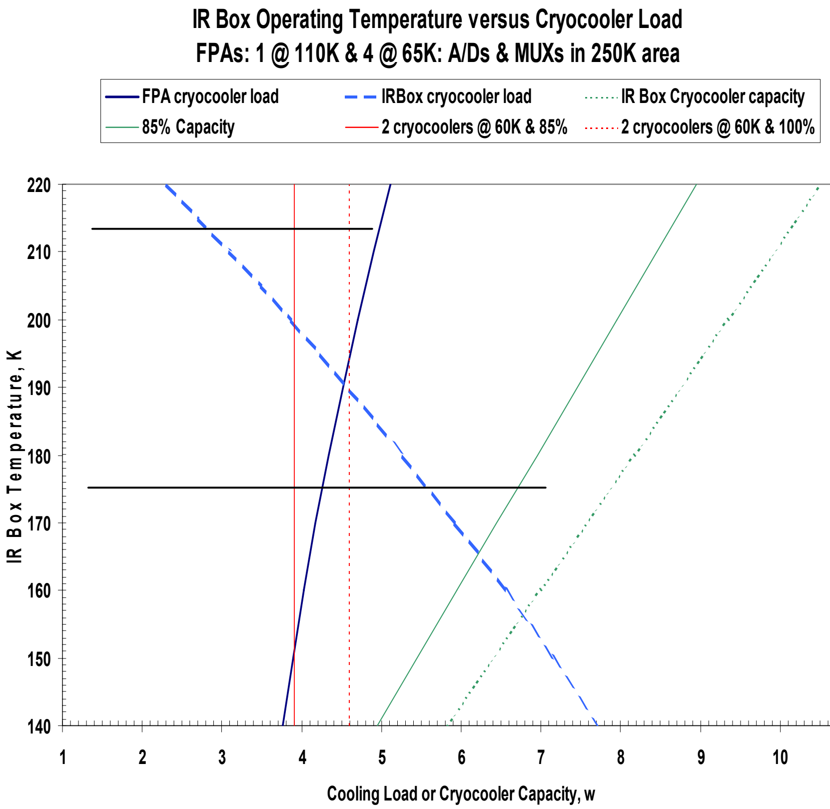




Operating Temperatures for 5 FPAs



- Shortwave channels eliminated

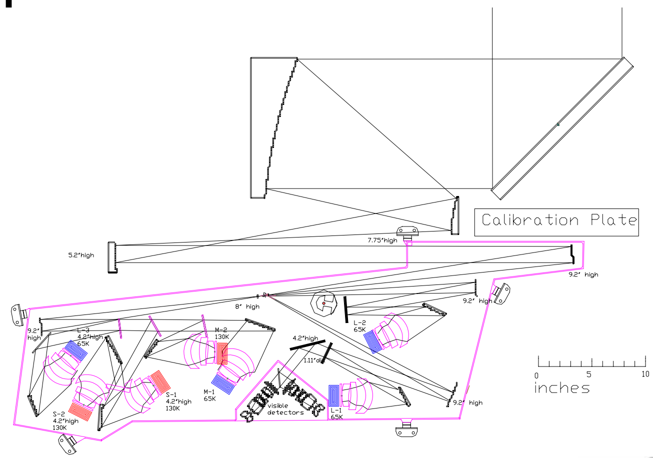


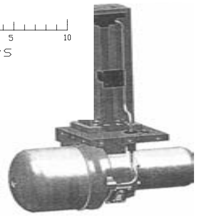
Implementation of Thermal Requirements

- Enclose grating assemblies in 155K housing to minimize ΔTs
  - thermally insulate from main optical bench

Heat Source	Heat Input (W)
7 FPA configuration	
Radiation to Housing	.166
Insulators	.309
Conduction Thru Wires	.287
FPA Power Dissipation	2 .657
Radiation to Cold Straps	.260
Total For FPAs	3.679
Cryocooler Cold Straps	.121
Non-Operating Cryocooler	.800
Total 65K Heat Load	4.600

2 Cryocooler capacity at 60K = 4.6 w





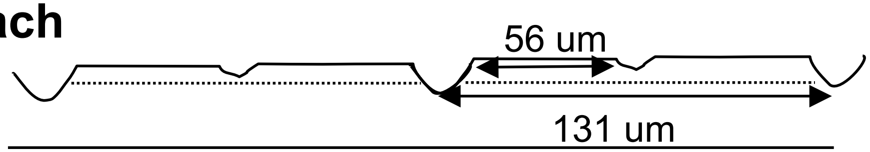
From AIAA Paper #99-4564
High Efficiency Cooler

"…experience indicates that around a 10-20% load increase may be expected on-orbit due to contamination of low-ε surfaces…" : Reference: Cryocooler Load Increase due to External Contamination of Low-ε Cryogenic Surfaces, R. G. Ross, Jr., Jet Propulsion Laboratory, June 18-20, 2002, International Cryoocooler Conference

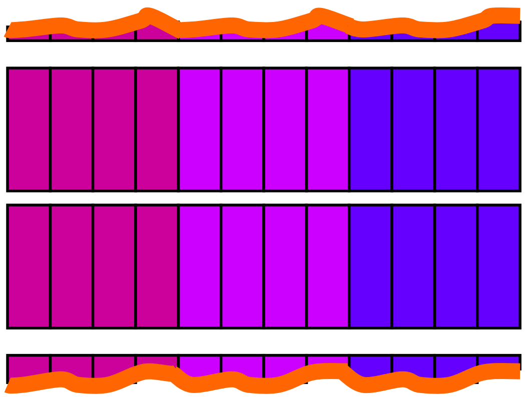
- The 7 FPA configuration will require cryocoolers operating at 100% capacity
- The 5 FPA configuration will allow cryocoolers to operate 85% - 90% capacity

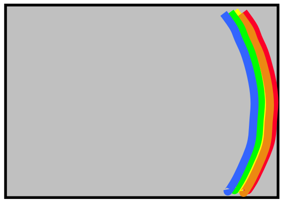
FPA Format Changes

- Format changes required to maintain spectral purity
- FPA still detects 96 ground spots, each 10 km vertical
  - Two spatial FPA pixels for each 10 km resolution element



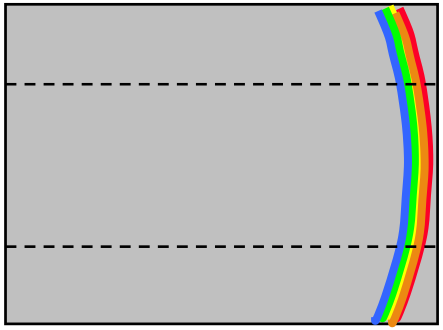
- Modified FPA format
  - All pixels halved in width
  - 8 pixels per resolution element instead of 2 in the previous design
  - Improves the spectral purity
  - 4 samples in each resolution element, instead of 1, facilitates sampling the curvature of slit images along the length of the array





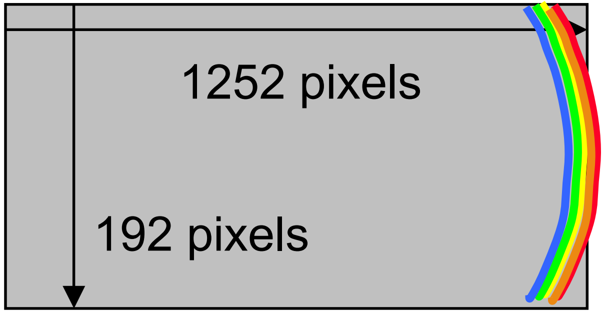
Multiple Narrow FPA Pixels

- "Slope" of slit image curvature is ~ 4.4 to 1; pixel sizing chosen to compensate.
  - On average, there is a 30 um shift in the horizontal center of the spectral sample for every ground patch of 2 vertical pixels
  - Curvature increases with off axis element → undersize pixels slightly to match curve more closely
  - The pixel width is 27.5 um, with a vertical to horizontal ratio of 4.8 to 1 (mesa area ratio is 4.2 to 1)
  - In outer portions of FPA, spectral elements will shift by approx. one pixel horizontally for each vertical ground spot (2 pixels=10 km)
  - Effect is systematic and thus could be calibrated, within constraints of thermal stability



ABS Grating Design FPA format

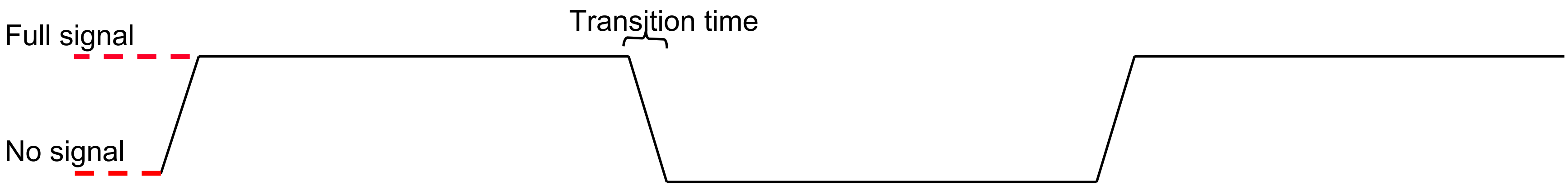
- **LW FPAs are (96x2) pixels by 1252 pixels, covering 96 spatial elements by 145 spectral elements**
  - Two spatial pixels cover 10 km
  - Curved image of slit requires extra pixels
  - Equivalent of ~600 x ~600 array
  - Pixels: 71 um (tall) x 28 um (wide)
  - Implies maximum charge capacity of 0.55 x10^8 e^- for each pixel
  - Newer, smaller, lower power (4uW/pixel) CTIA Preamps still fit small pixel



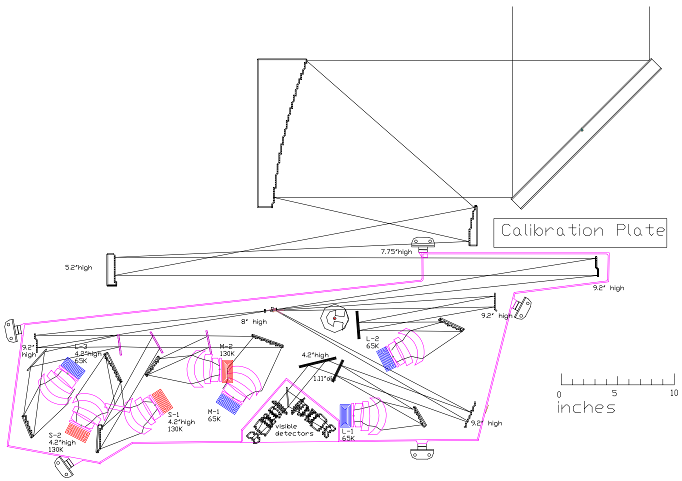
- **Several FPAs in design use multiple reads; accommodates chopper in LW1 and avoids saturating charge storage capacitors**
  - Multiple reads of 8,3,3,1,and 1 are used for LW1, LW2, LW3, MW1, and MW2 respectively
  - Multiple FPA outputs are used to read the 120192 pixels per FPA: 192, 32, 16, 6, 6 outputs are used in LW1, LW2, LW3, MW1, and MW2 respectively
  - Multiple outputs reduce rate of each to <0.32 Mpix/sec, reducing noise.

Mechanical Chopper Added in LW1

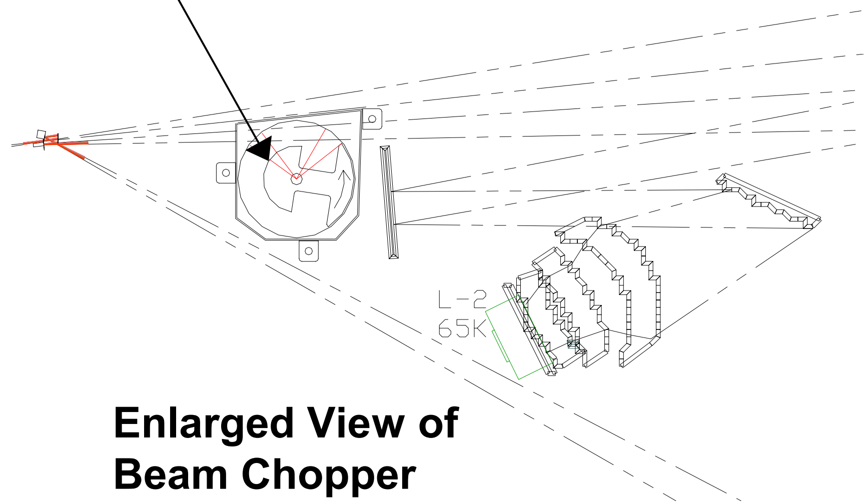
- **Waveform below shows light level transmitted to FPA**
  - **45% of time the signal integrates, 45% of time reference integrates, 10% transition times**
- **Chopper runs at 22.22 Hz permitting 4 signal images and 4 reference level images for each ground footprint**
- **Chopper minimizes 1/f noise while improving operability for longest waveband FPA (LW1)**
  - **Chopper rate is ~75x “best” pixel knee frequency but only 1 to 0.2x knee frequencies of other pixels**
- **FPA must be read out during the chopper bright/dark transitions → faster rate than no-chopper design**



LW1 Beam Chopper



Rotating beam chopper location



Enlarged View of Beam Chopper

- Estimated mass increase of ~ 2 kg
- Small power increase for motors and heaters
- Use heater power to maintain constant temperature

ABS Grating Design: Summary of IR Spectral Regions

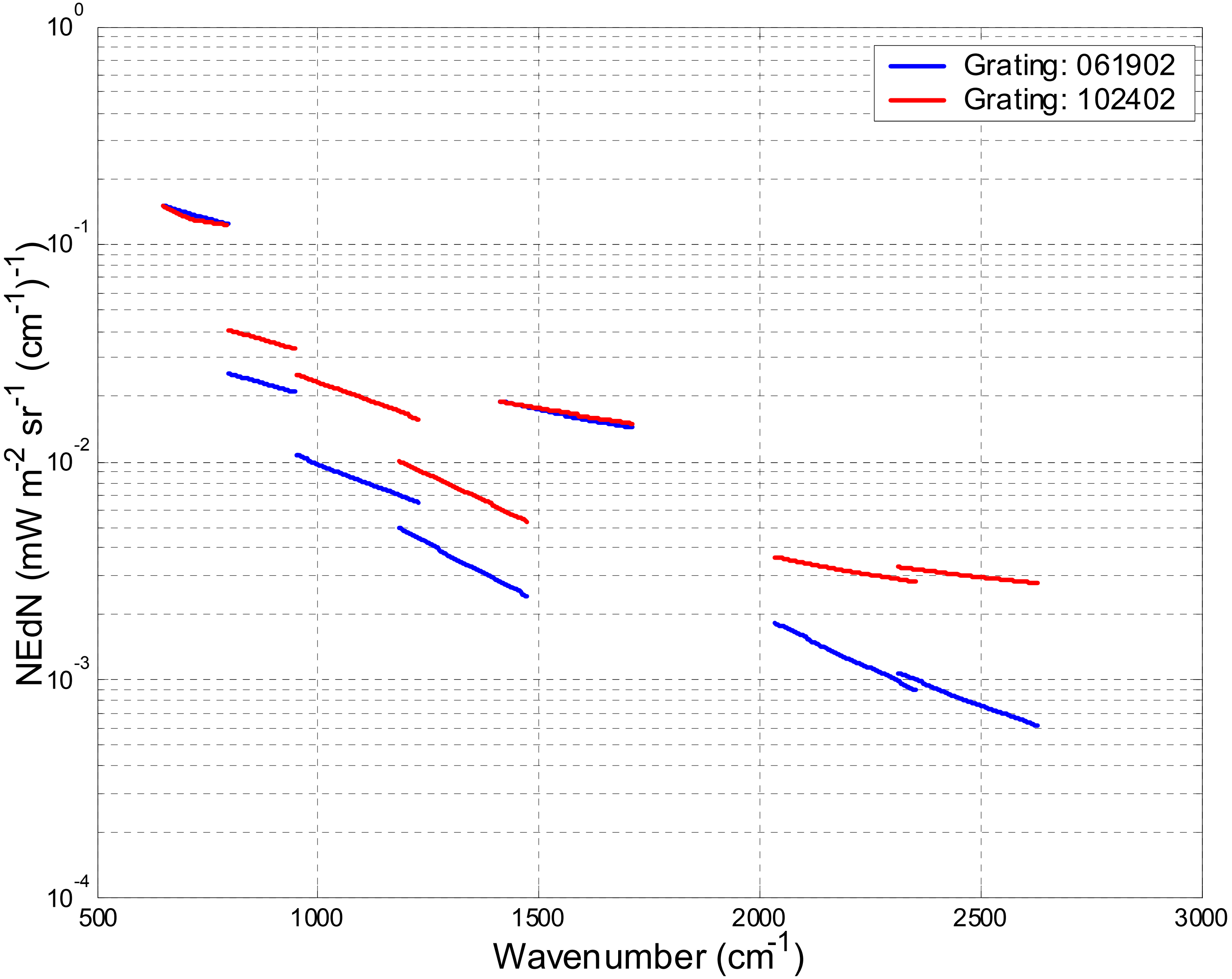
Spectral Region	Spectral resolution	Number of spectral bins
LW1: 15.4 – 12.54 um	0.0196 um	145
LW2: 12.54 – 10.54 um	0.0130 um	145
LW3: 10.53 – 8.13 um	0.0083 um	290
MW1: 8.44 – 6.78 um	0.0057 um	290
MW2: 7.08 – 5.84 um	0.0043 um	290
SW1: 4.91 – 4.25 um	0.0023 um	290
SW2: 4.32 – 3.80 um	0.0018 um	290

- **Coverage of 5 spectral regions, instead of 7, provides performance that meets 1 K rms temperature error and 10% relative humidity error, as demonstrated in subsequent talk**
- **The wavenumber (cm^{-1}) resolution requirement was chosen at one point – the shortwave side of spectral region for each grating**
  - **All IR bands provide resolution of ~ 1.25 cm^{-1}**

Continuous Scanning vs. Step and Stare

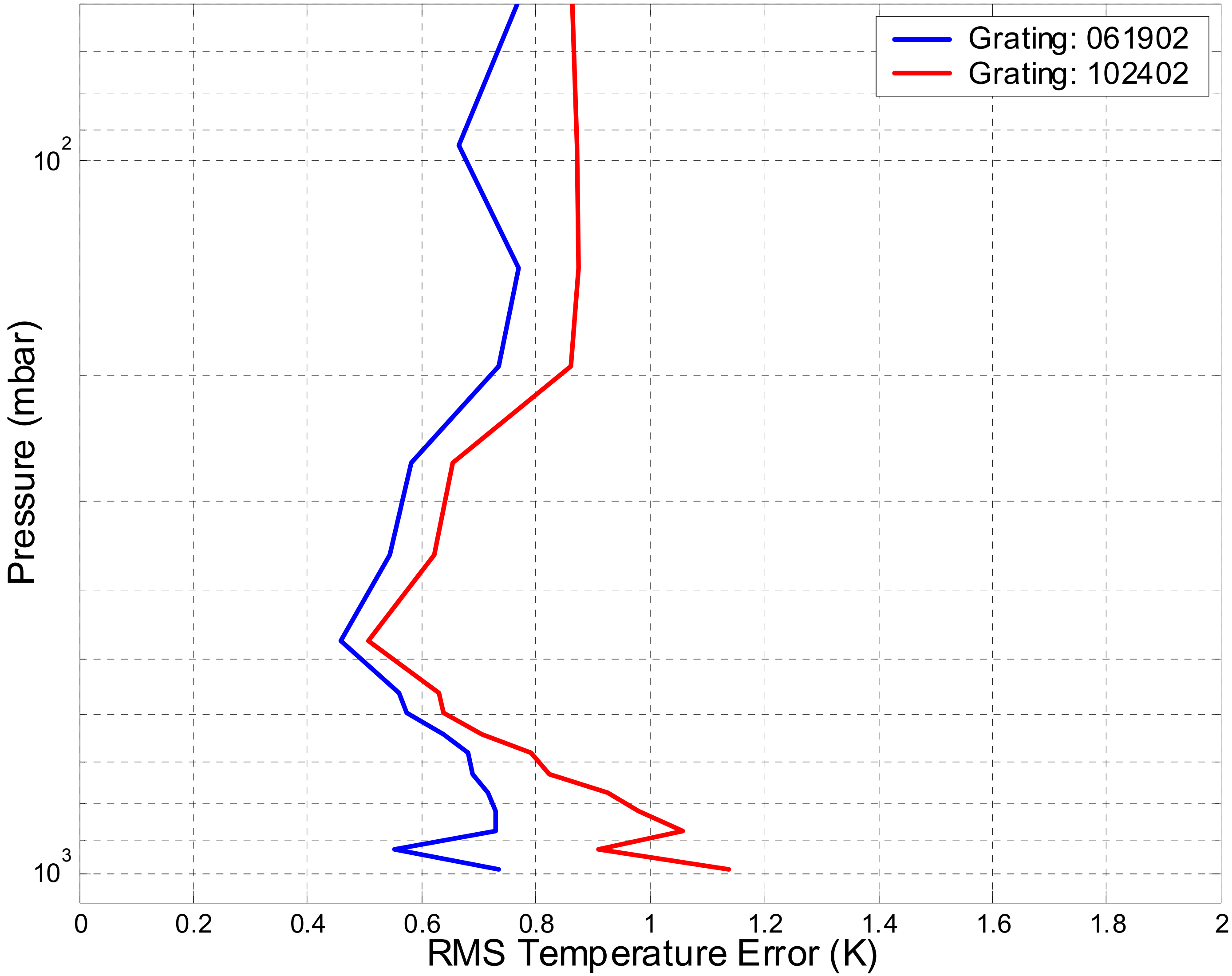
- **Step and stare motion**
  - Mirror must settle before data collection
  - Starting and stopping mirror imparts torques to spacecraft comparable to those of current sounder, which should be acceptable
  - Permitted integration plus FPA readout time is 0.21 second.
- **Continuous scanning motion**
  - Mirror is either rotated slowly at a constant rate or stepped in small increments with the mirror momentum providing a smooth mirror motion
  - Torques imparted to the spacecraft are about twice the current imager's and at least an order of magnitude larger than future advanced imager estimates
  - Sweeping mirror effectively smears the earth scene over a larger area, impacting the MTF
  - Permitted integration plus FPA readout is 0.23 second.
- **Difference in NEDNs is negligible (<1% at longest wavelengths and < 6% at 4 um)**

Inputs to Sounding Retrieval Model



Red = 5 band
Blue= 7 band

Temperature Retrieval Model Results



Red = 5 band
Blue= 7 band

Summary

- MIT/LL has essentially completed a point-design study for a grating-based ABS instrument
- Design has evolved over numerous iterations
- Key modifications from last quarterly (June ‘02)
  - FPA format
  - Mechanical chopper
  - Cryo-cooler configuration
- Present grating design appears marginally feasible, but very challenging
  - Thermal and optical systems could prove too aggressive
  - Alternative optical design option does exist, but hasn’t been explored in detail

A Neural Network Retrieval Technique for Hyperspectral Sounding

William J. Blackwell

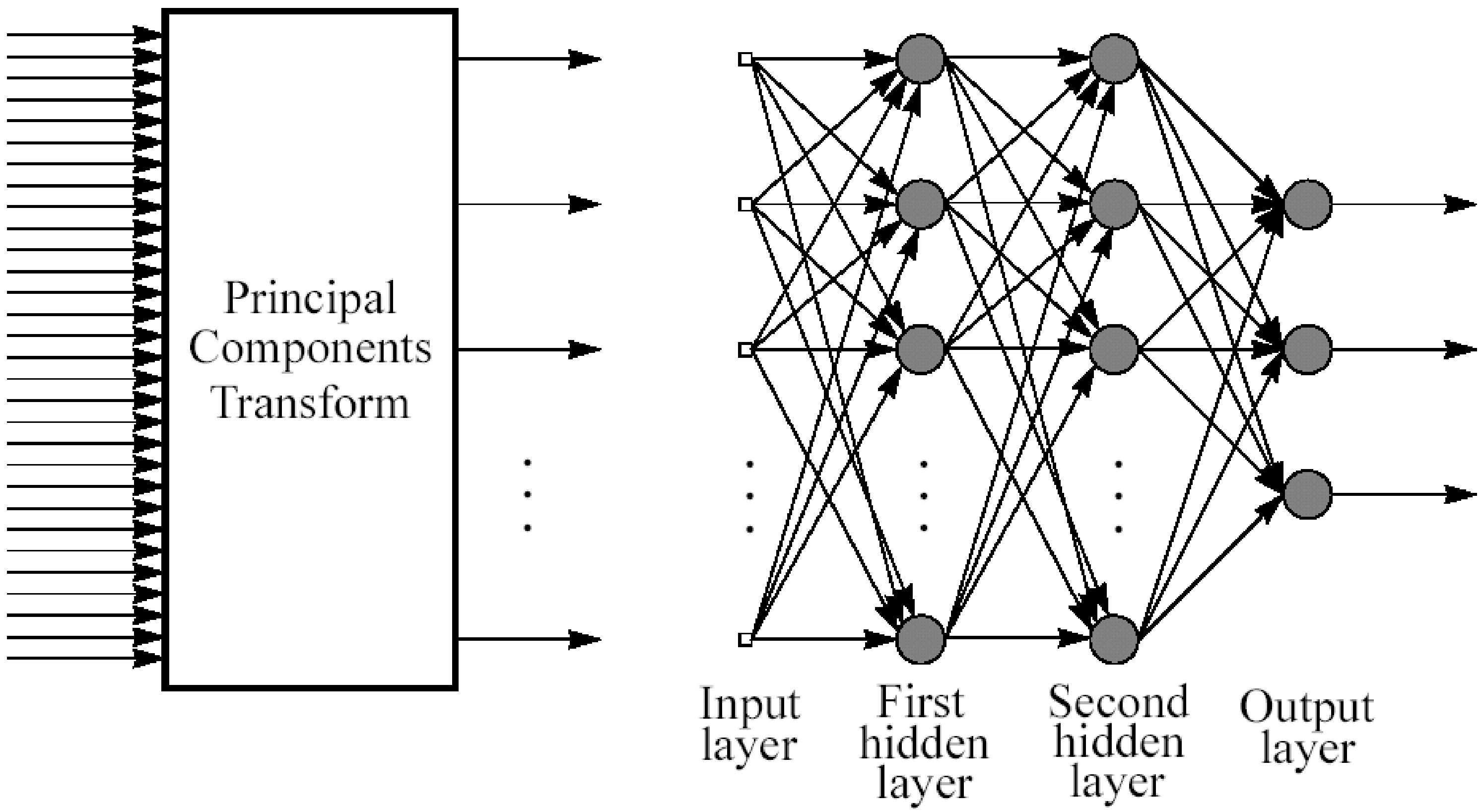
GOES Quarterly Review

22-24 October, 2002

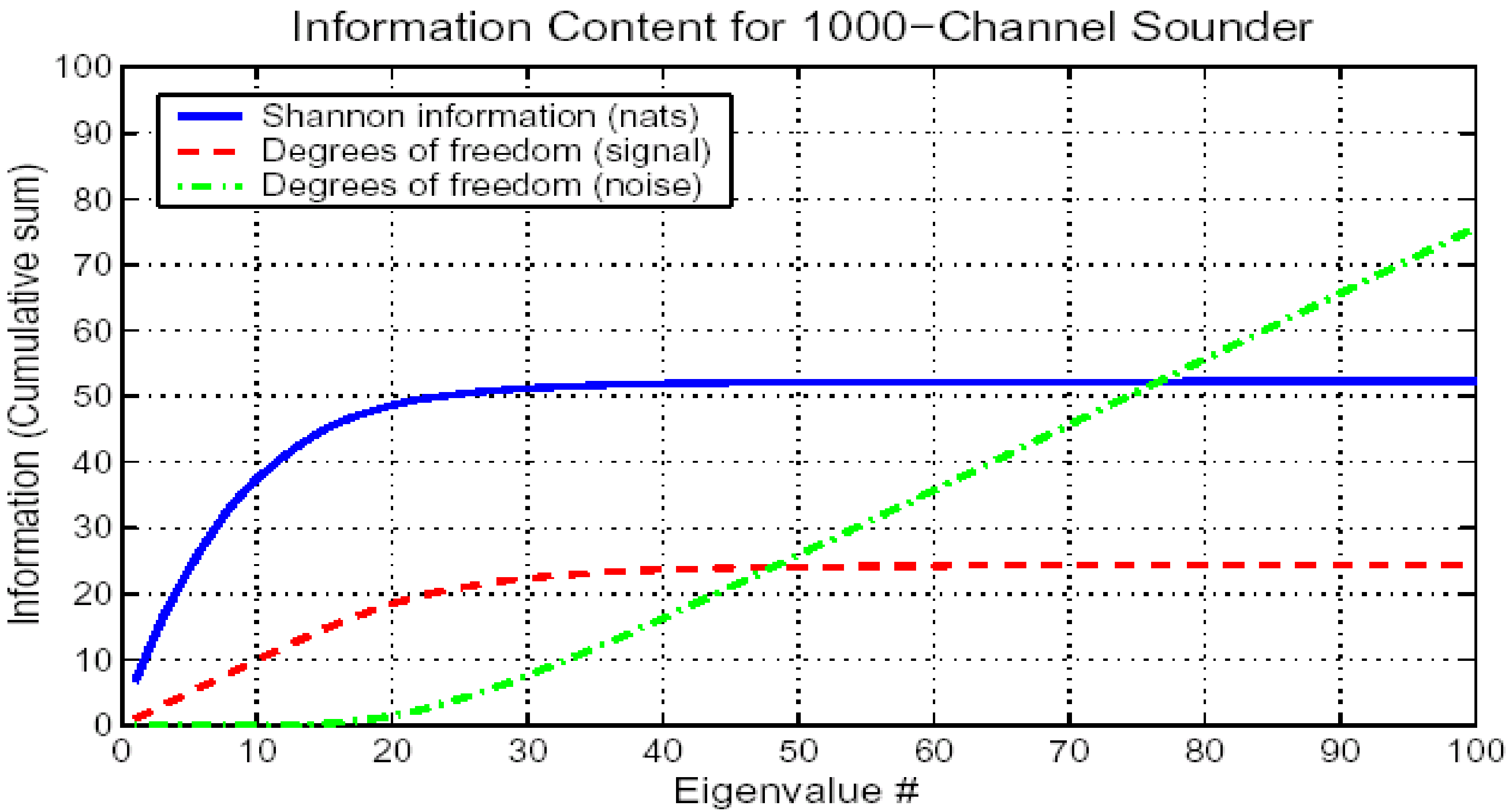
Outline

- Overview of algorithm
- Compression of hyperspectral sounding data:
  - Principal components analysis (PC, NAPC, PPC)
- Introduction to neural networks
- Examples/comparisons

Combination of Compression and Neural Network

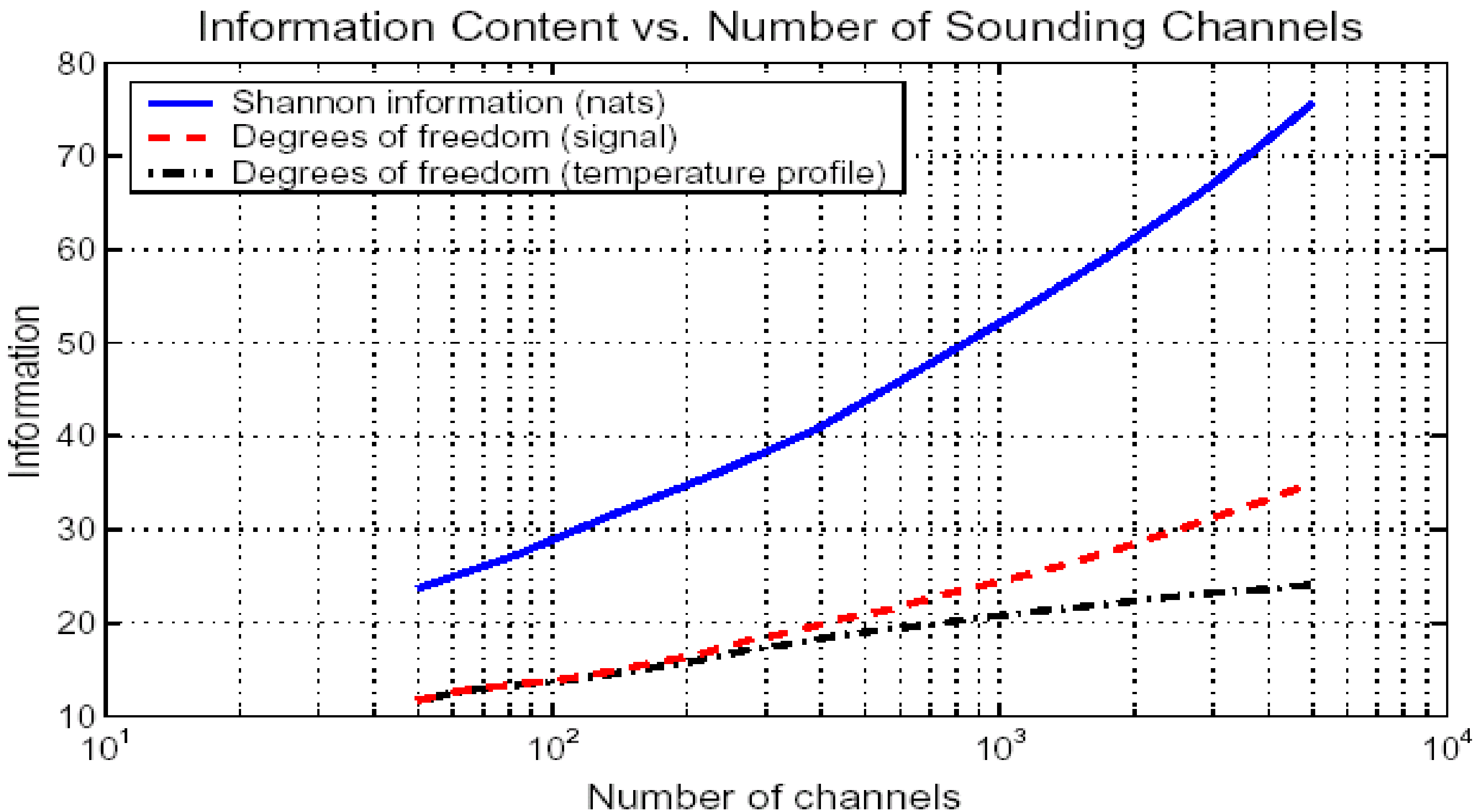


Hyperspectral Sounding Data is Highly Correlated



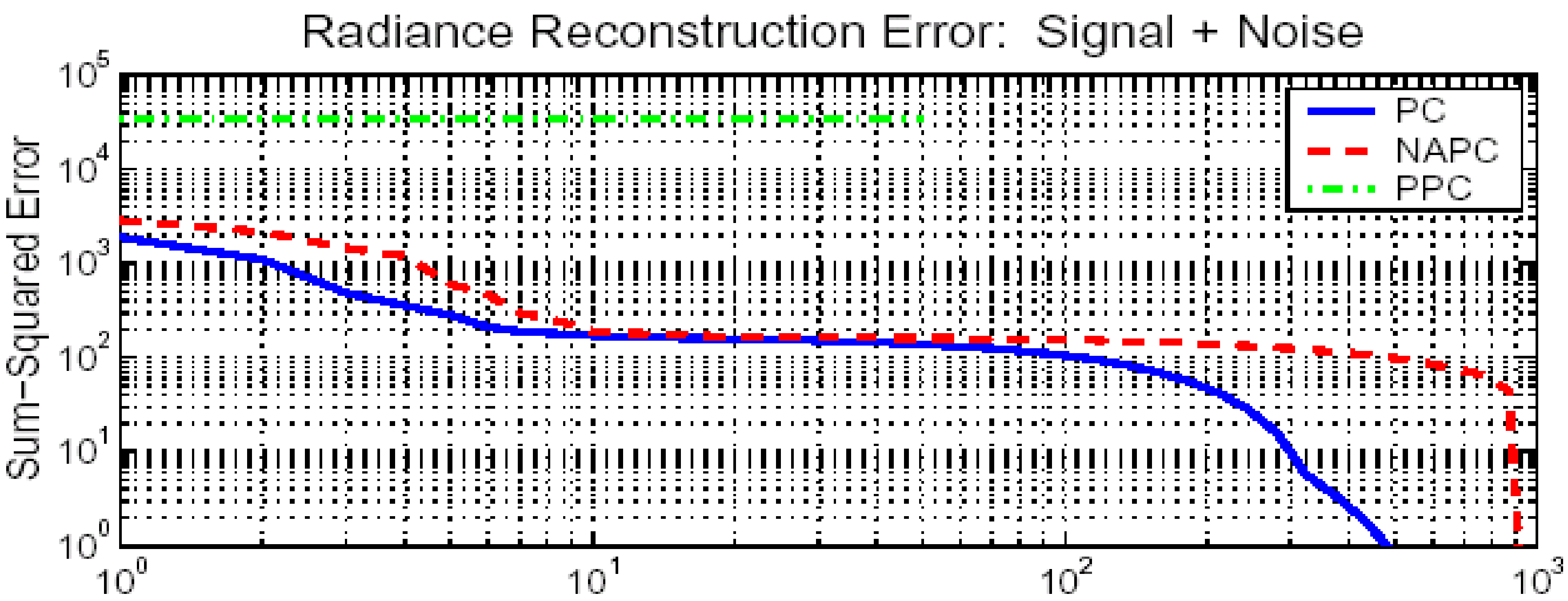
$$I = \frac{1}{2}\sum_i \log(1+\lambda_i) \qquad \mathrm{DOF_s} = \sum_i \frac{\lambda_i}{1+\lambda_i} \qquad \mathrm{DOF_n} = \sum_i \frac{1}{1+\lambda_i}$$

Hyperspectral Sounding Data is Highly Correlated



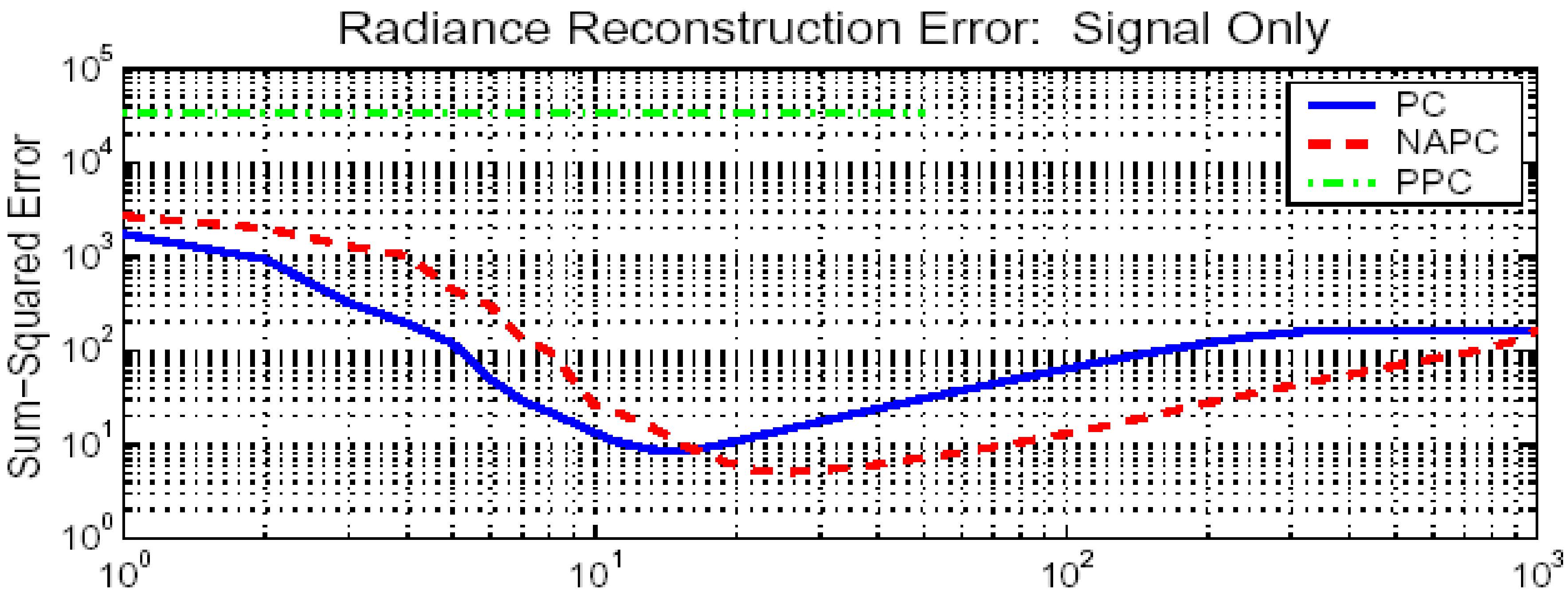
$$I = \frac{1}{2}\sum_i \log(1+\lambda_i) \qquad \mathrm{DOF_s} = \sum_i \frac{\lambda_i}{1+\lambda_i} \qquad \mathrm{DOF_T} = \sum_i \frac{\varphi}{1+\varphi_i}$$

Principal Components Decomposition



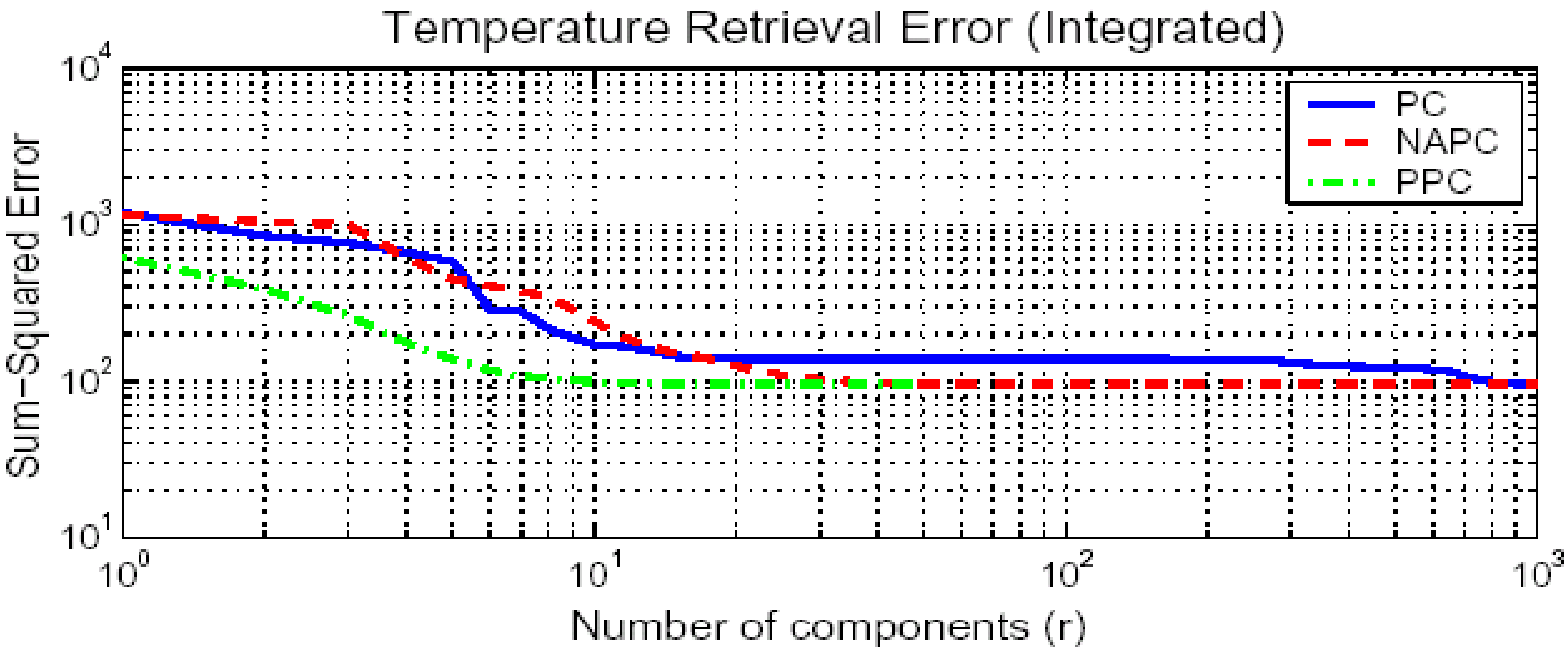
1000-channel sounder (4-15 μm)

Noise-Adjusted Principal Components Decomposition



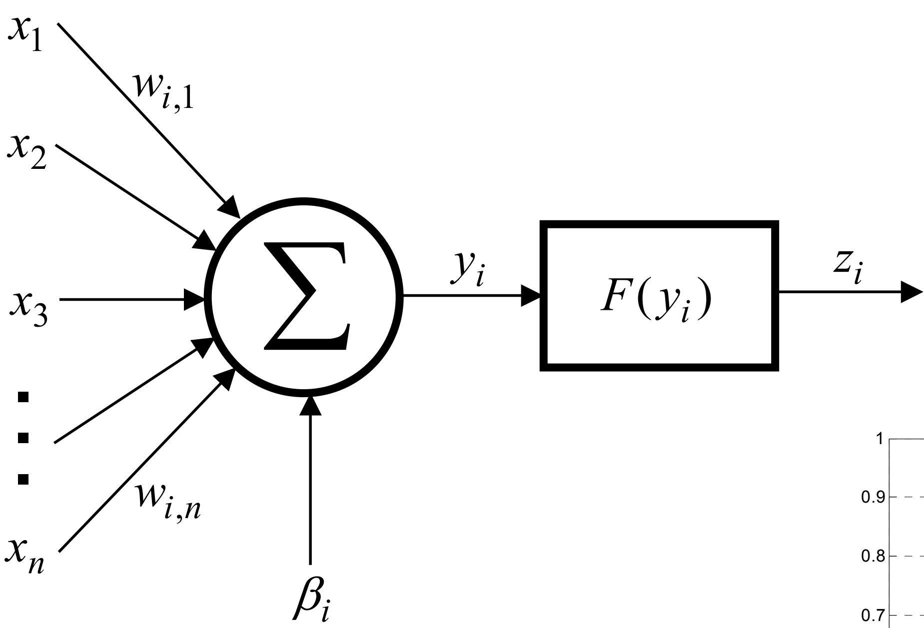
1000-channel sounder (4-15 μm)

Projected Principal Components Decomposition



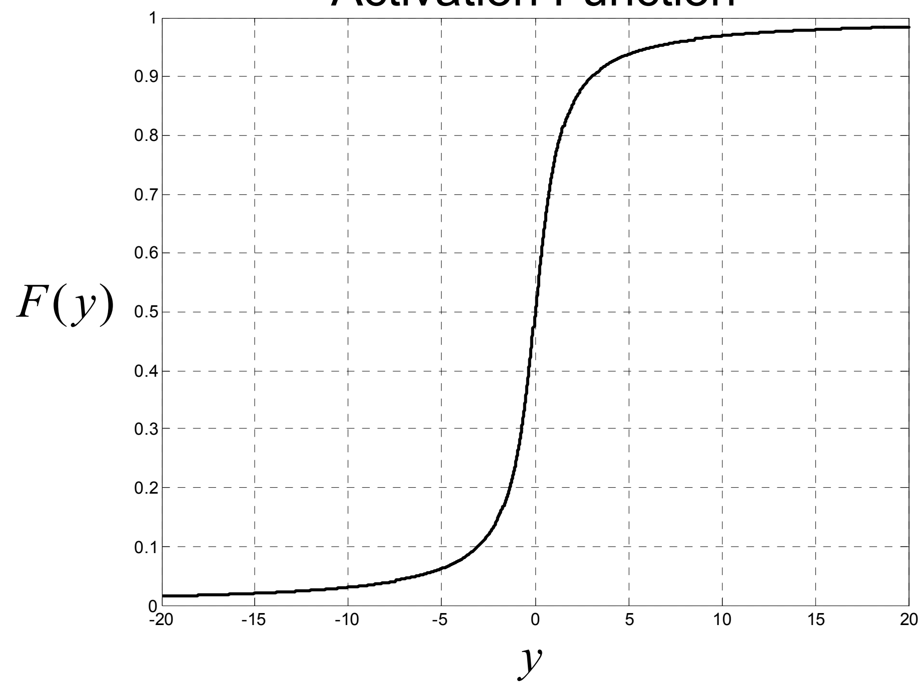
1000-channel sounder (4-15 μm)

Perceptron



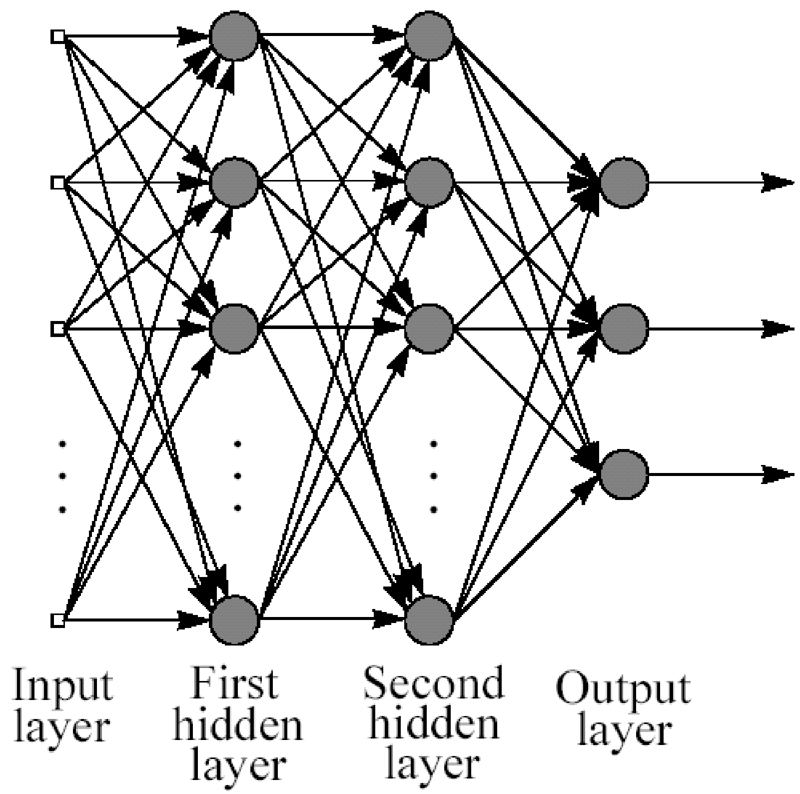
Differentiable activation functions typically used to facilitate gradient searches

"Activation Function"



Perceptron weights and biases are iteratively adjusted by "back propagation" of errors.

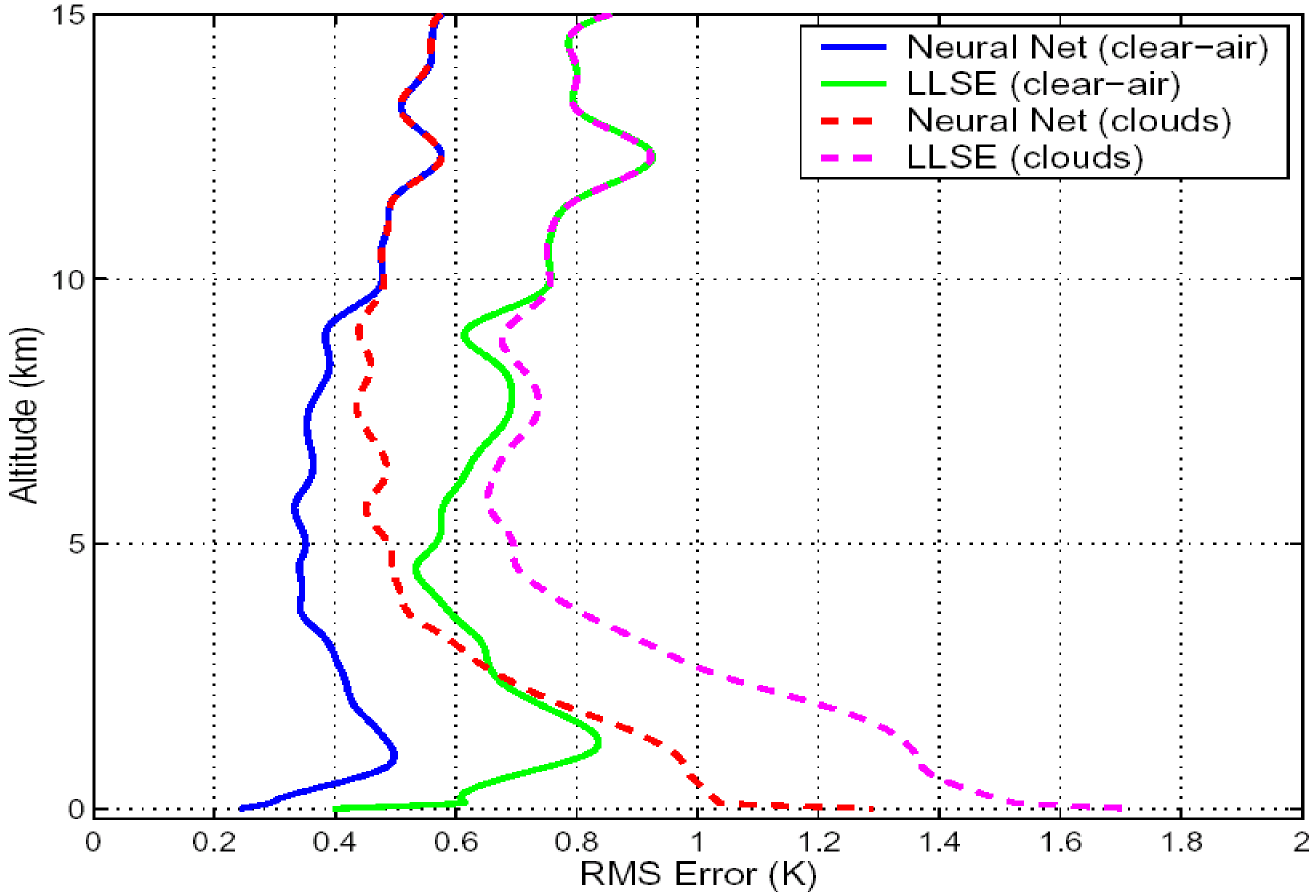
Feedforward Network of Multilayer Perceptrons



Temperature profile retrievals: One hidden layer of 30 nodes

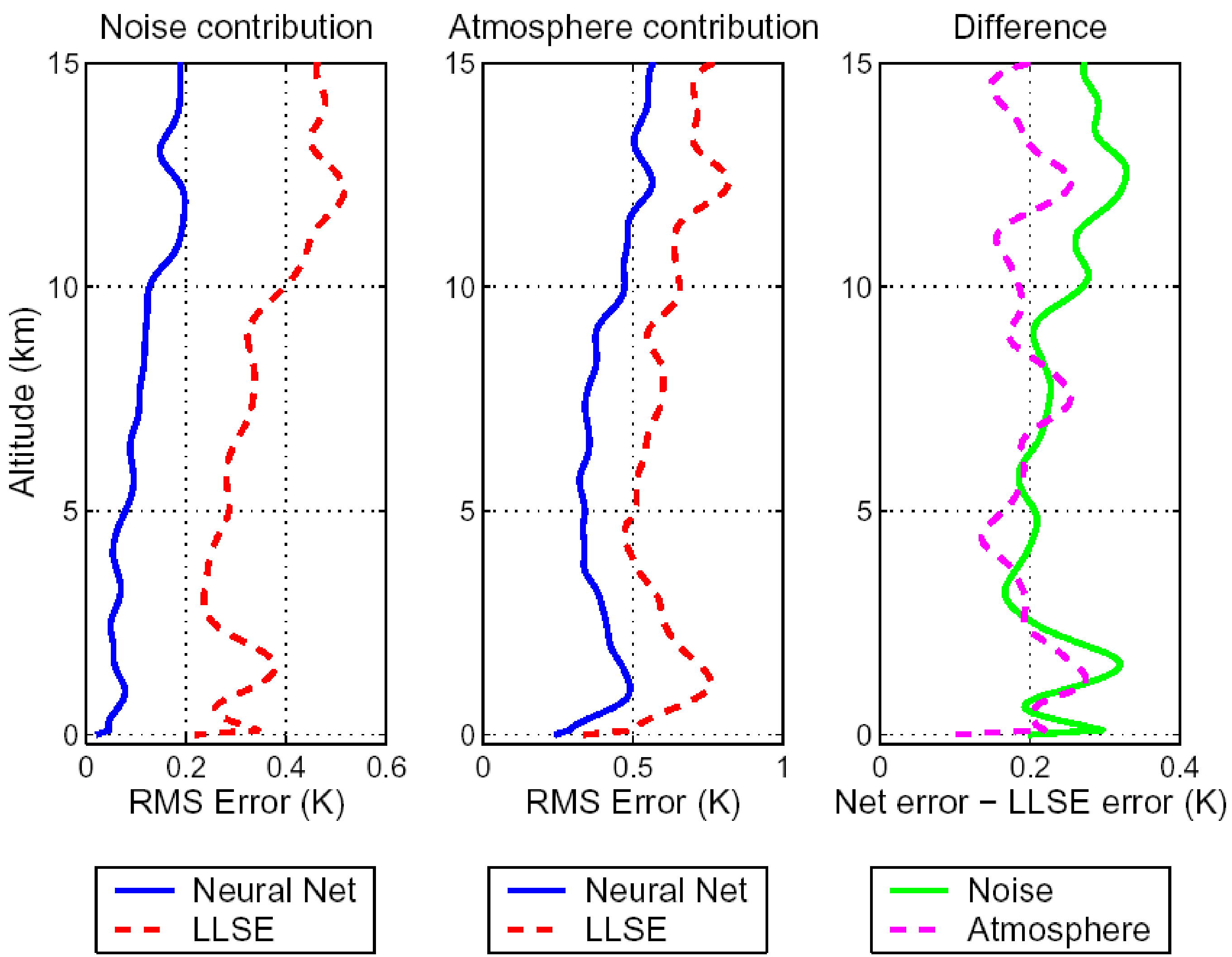
Relative humidity profile retrievals: Two hidden layers (30,15)

Temperature Profile Retrieval in Clear-Air and Clouds

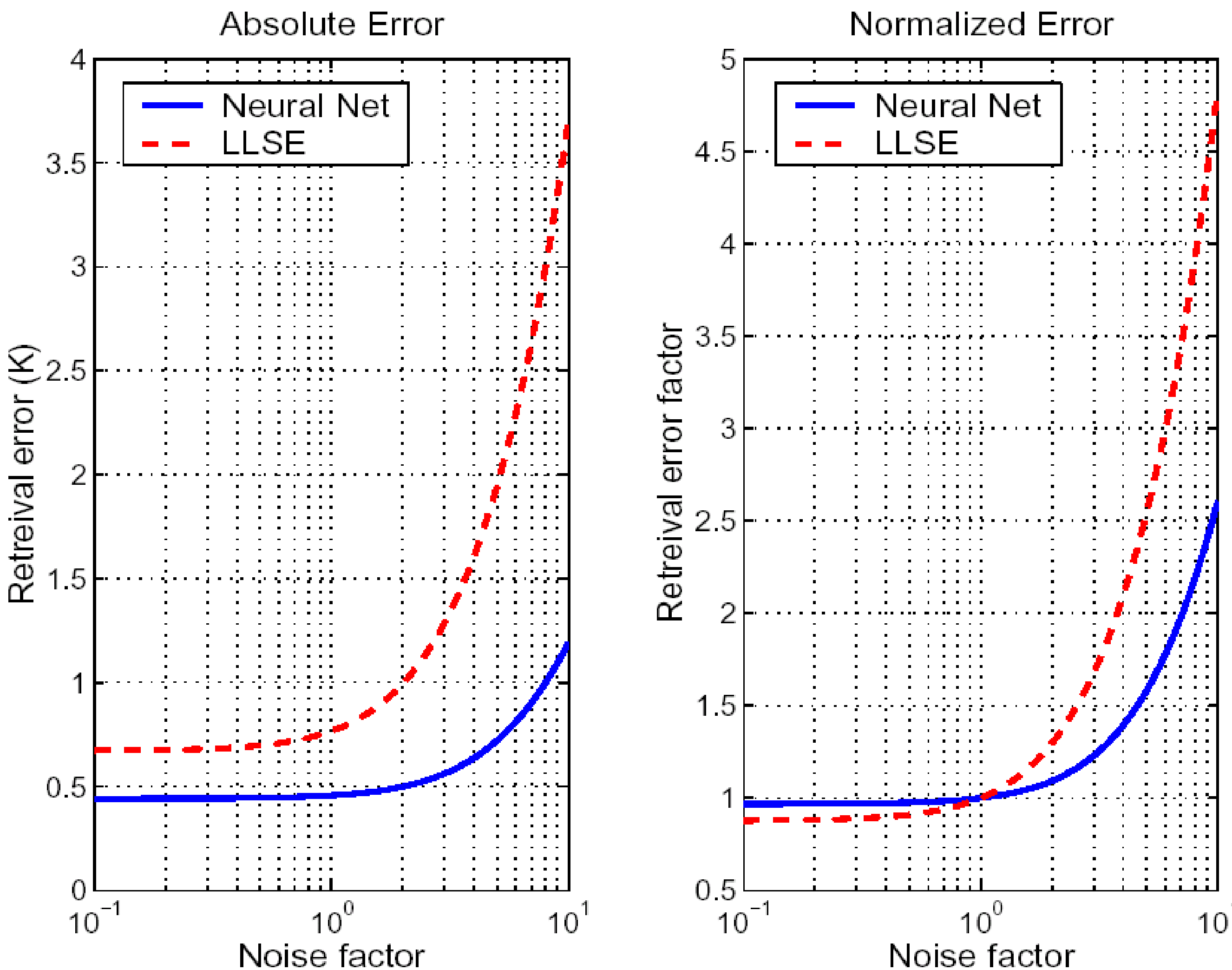


Simulated AIRS/AMSU-A/AMSU-B radiances were used

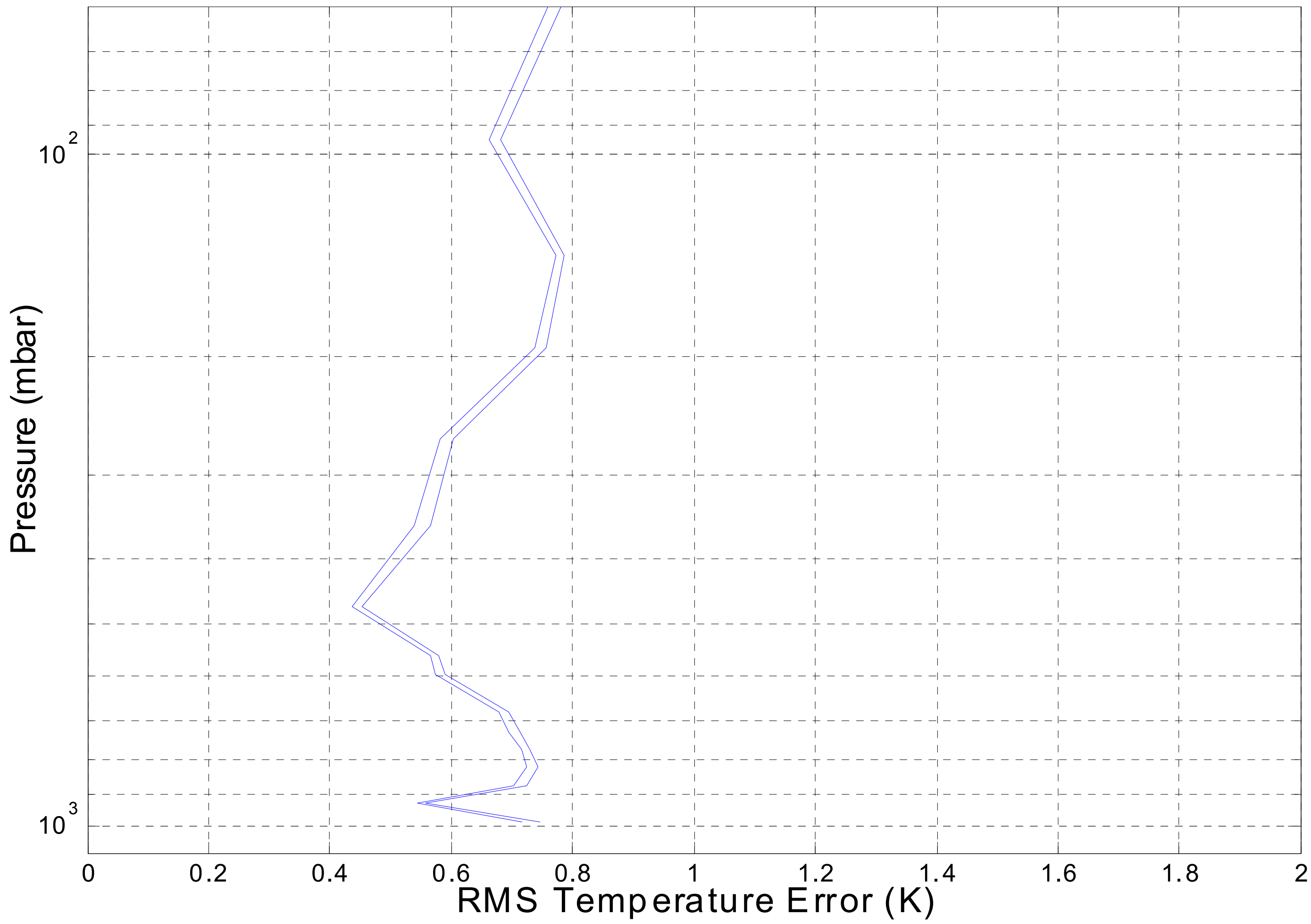
Error Contributions: Neural Network vs. Linear Regression



Sensitivity to Measurement Noise: Neural Network vs. Linear Regression

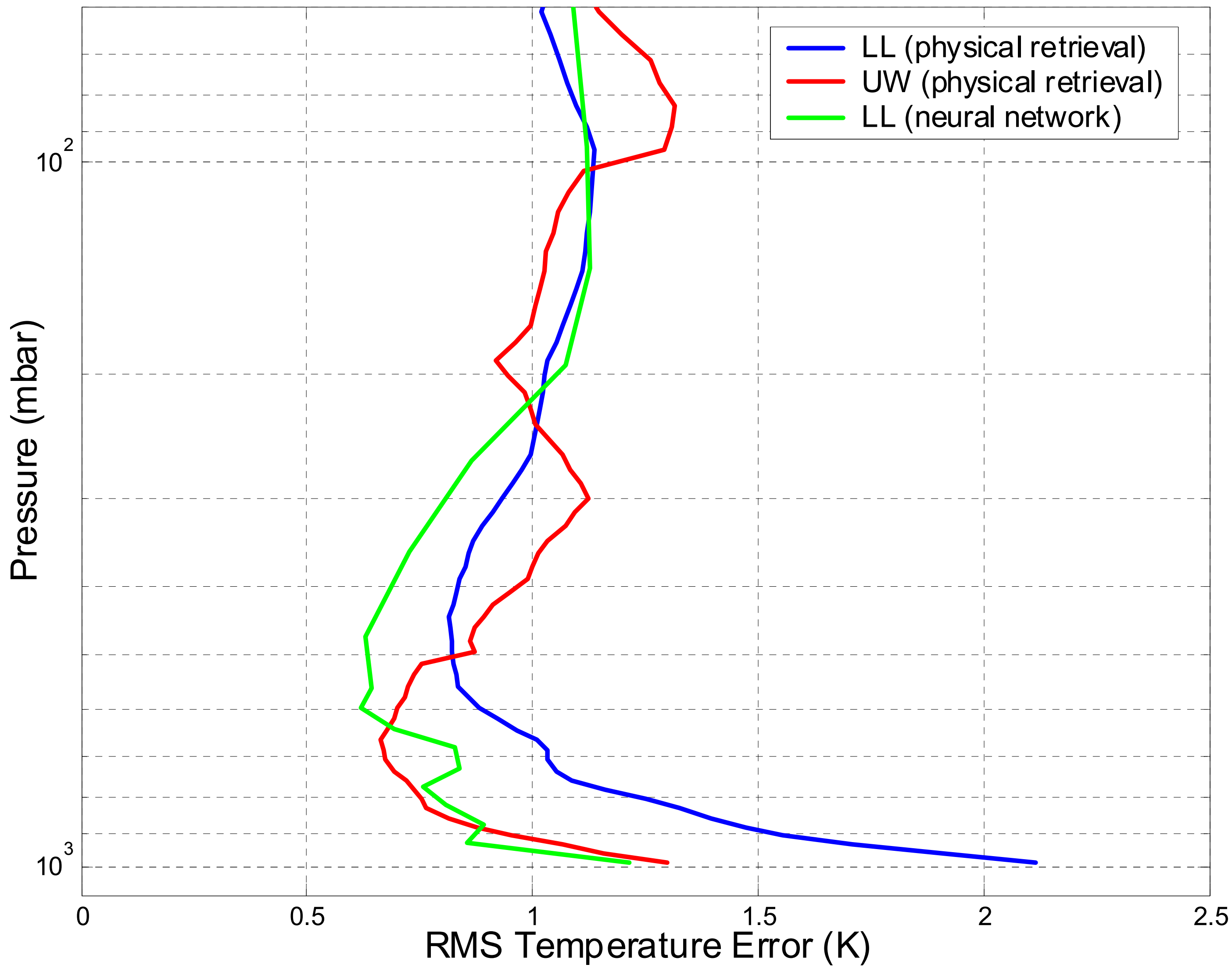


Neural Network Temperature Retrieval: Typical Error Bars

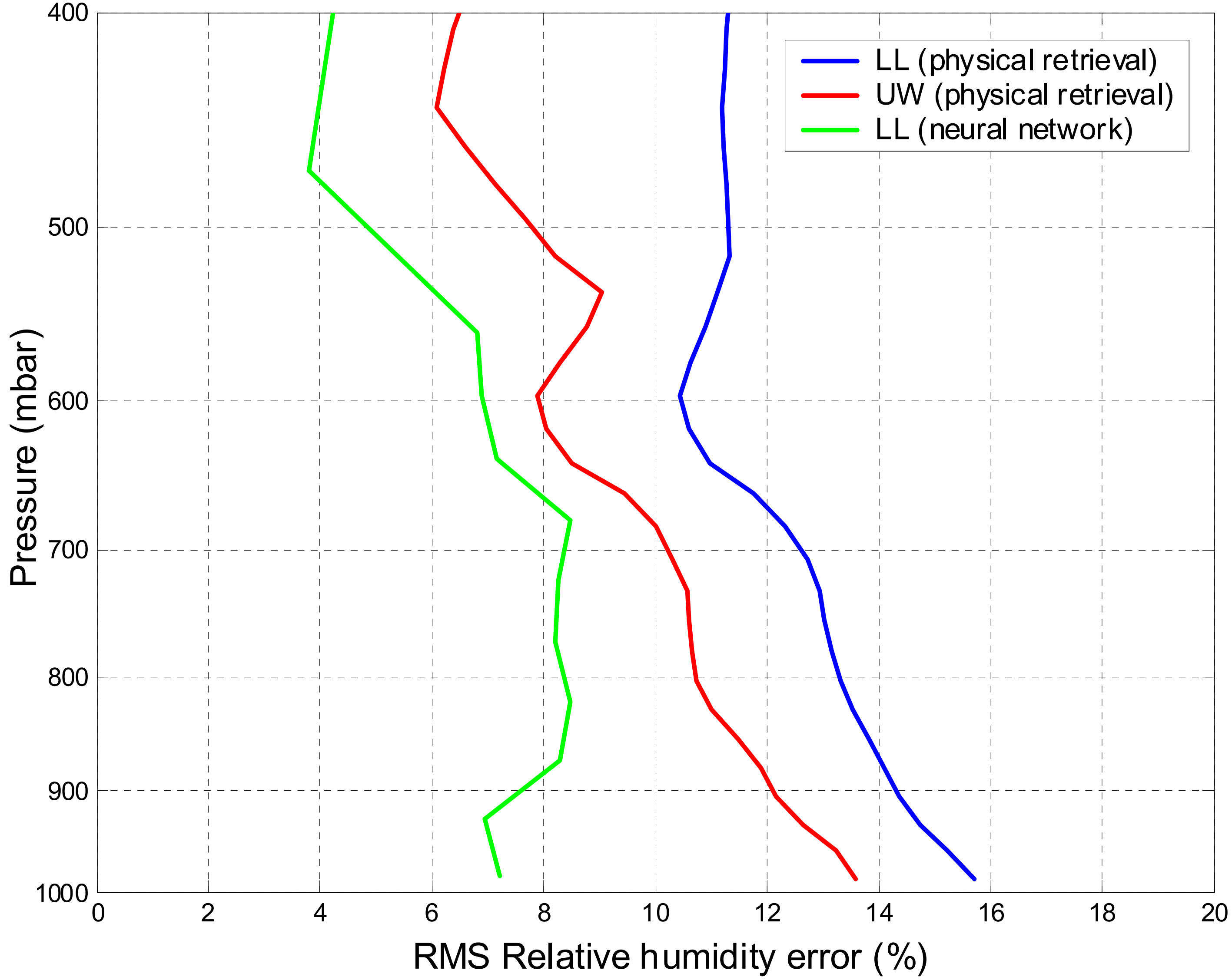


mean +/- one standard deviation is shown

Temperature Retrieval Performance: Neural Network vs. Physical Retrieval



Water Vapor Retrieval Performance: Neural Network vs. Physical Retrieval



Neural Network Computational Advantage

- Neural Network training/validation for 1000 profiles takes about an hour on a Pentium IV 2.5-GHz workstation (99.9% of which is for training).
- Physical/iterative methods can take up to 50 times longer, and require a reduced channel set.

Summary

- A profile retrieval method combining the Projected Principal Components transform and a neural network was developed and tested
- Significant performance advantages over linear regression
  - Better RMS error
  - Better noise immunity
- Performance meets or exceeds physical/iterative methods
  - Better noise immunity
  - Much faster

ABS Retrieval Simulations: Methodology and Results

William J. Blackwell, Monica Coakley, Harry Finkle

GOES Quarterly Review

22-24 October, 2002

Outline

- Review of geophysical properties of profile data
  - Profile statistics
  - Surface model
- Instrument assumptions:
  - NEΔN
  - Spectral resolution
  - Synthesis of spectral response functions (SRFs)
- Simulation Results
  - Impact of degraded spectral resolution
  - Impact of reduced spectral coverage
- Preliminary Operability Analyses
  - Interferometer
  - Grating

Outline

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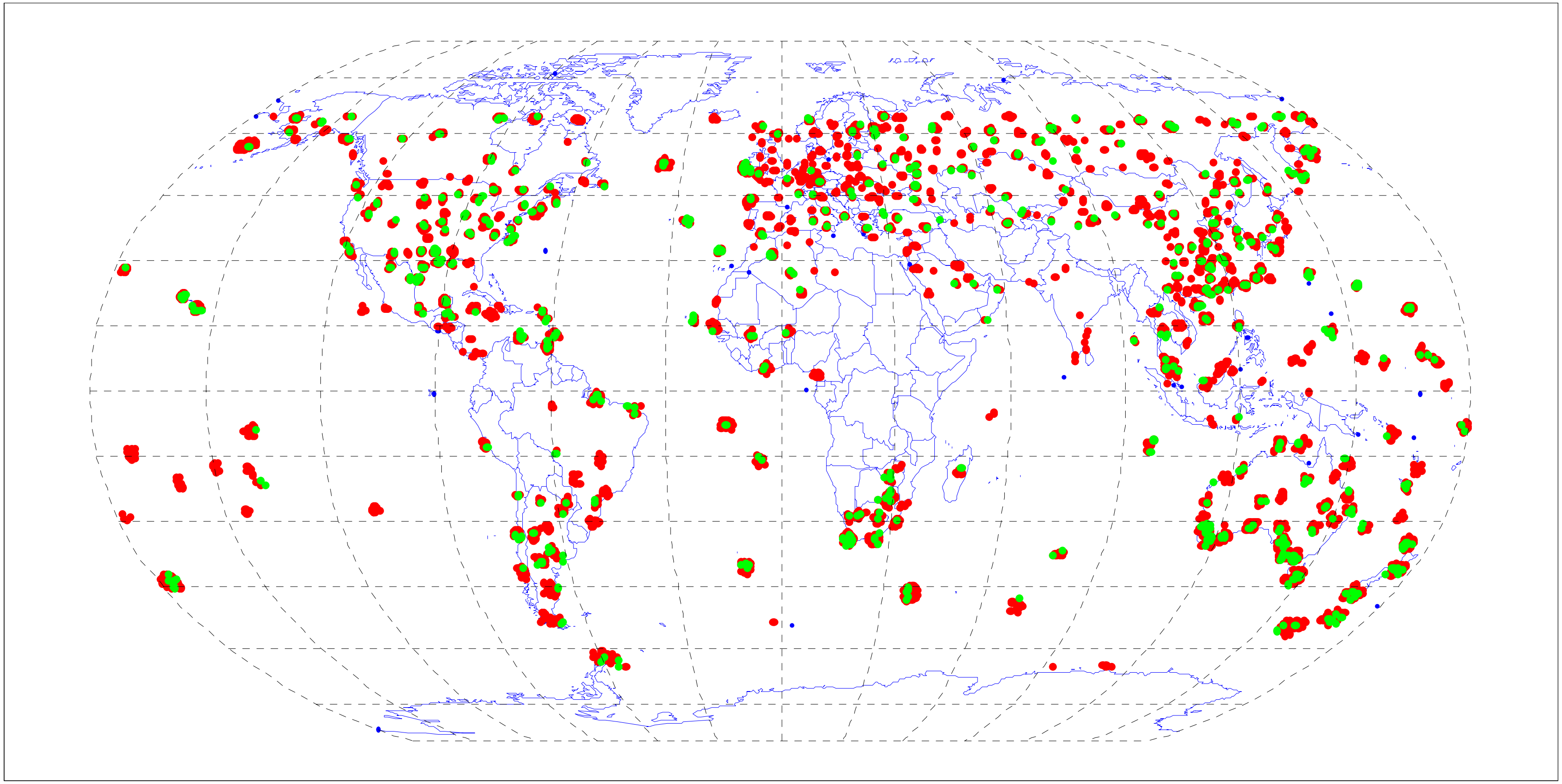
RAOB Geographical Distribution

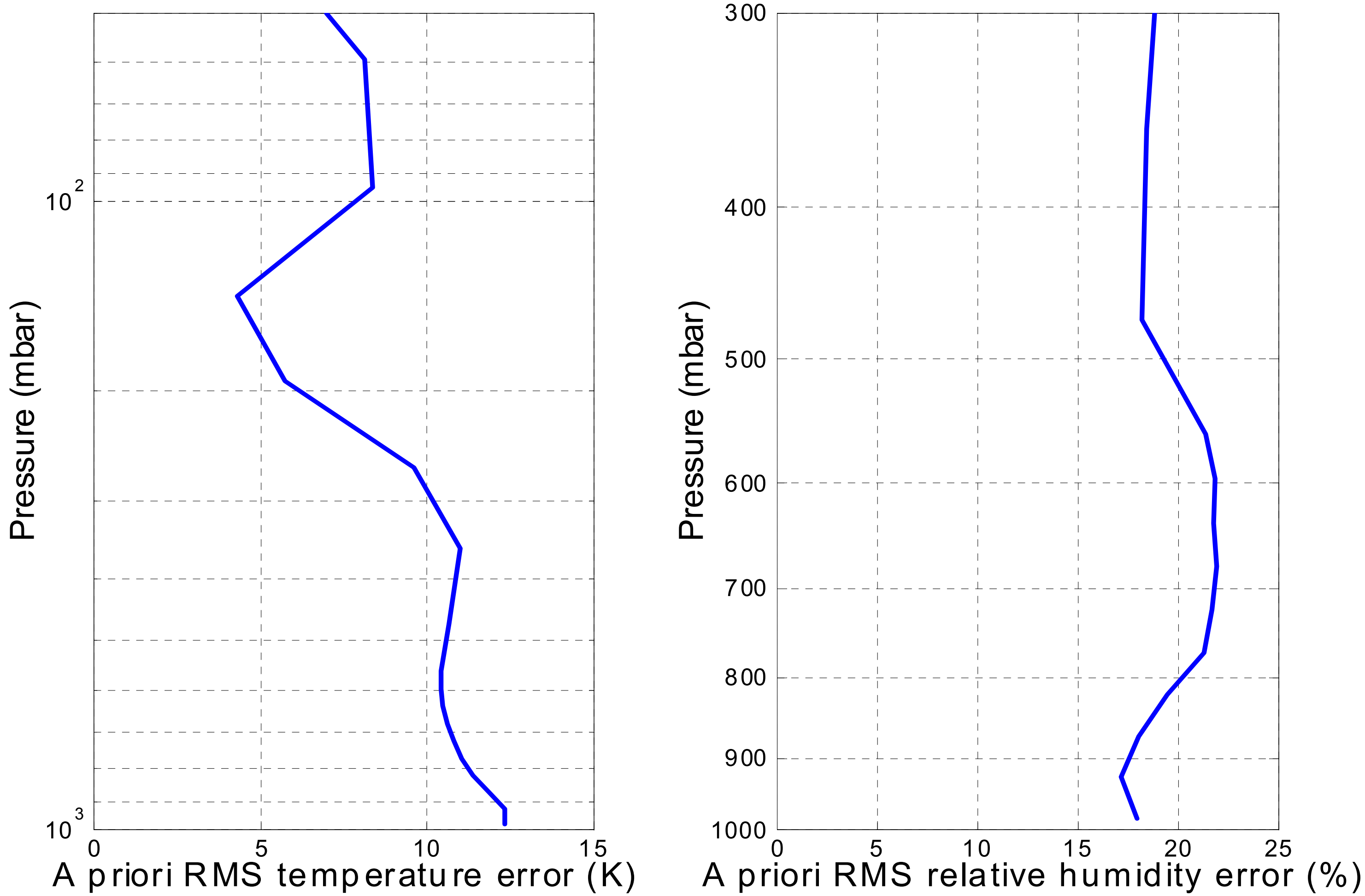


• Training (4765) • Validation (596)

~Uniformly distributed temporally & seasonally

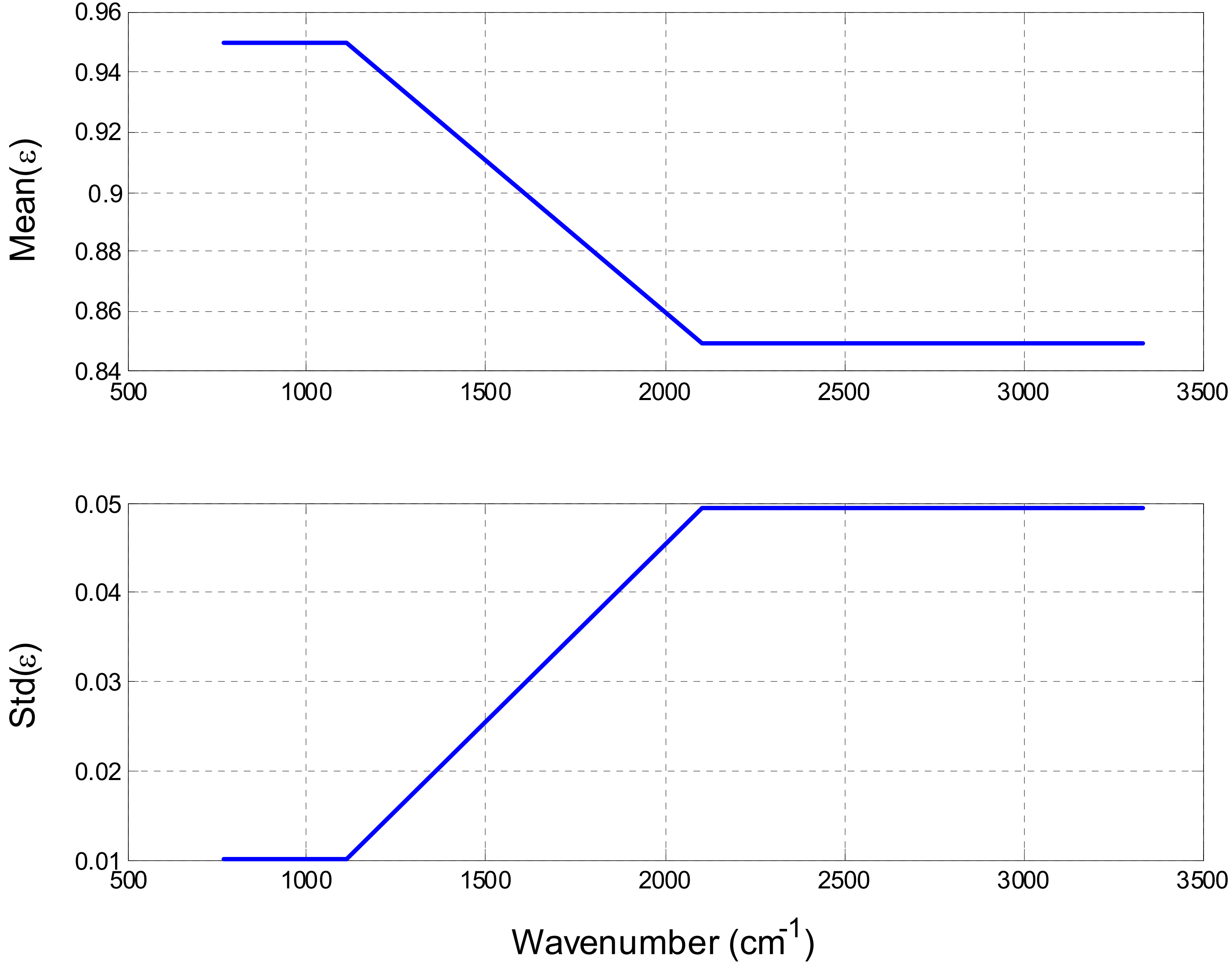
NOAA-88b

A Priori Profile Statistics



Layer averaging used: 0.5 km (0-5 km), 2 km (5-15 km), 3 km (15+ km)

Mean and Standard Deviation of Surface Emissivity Distribution



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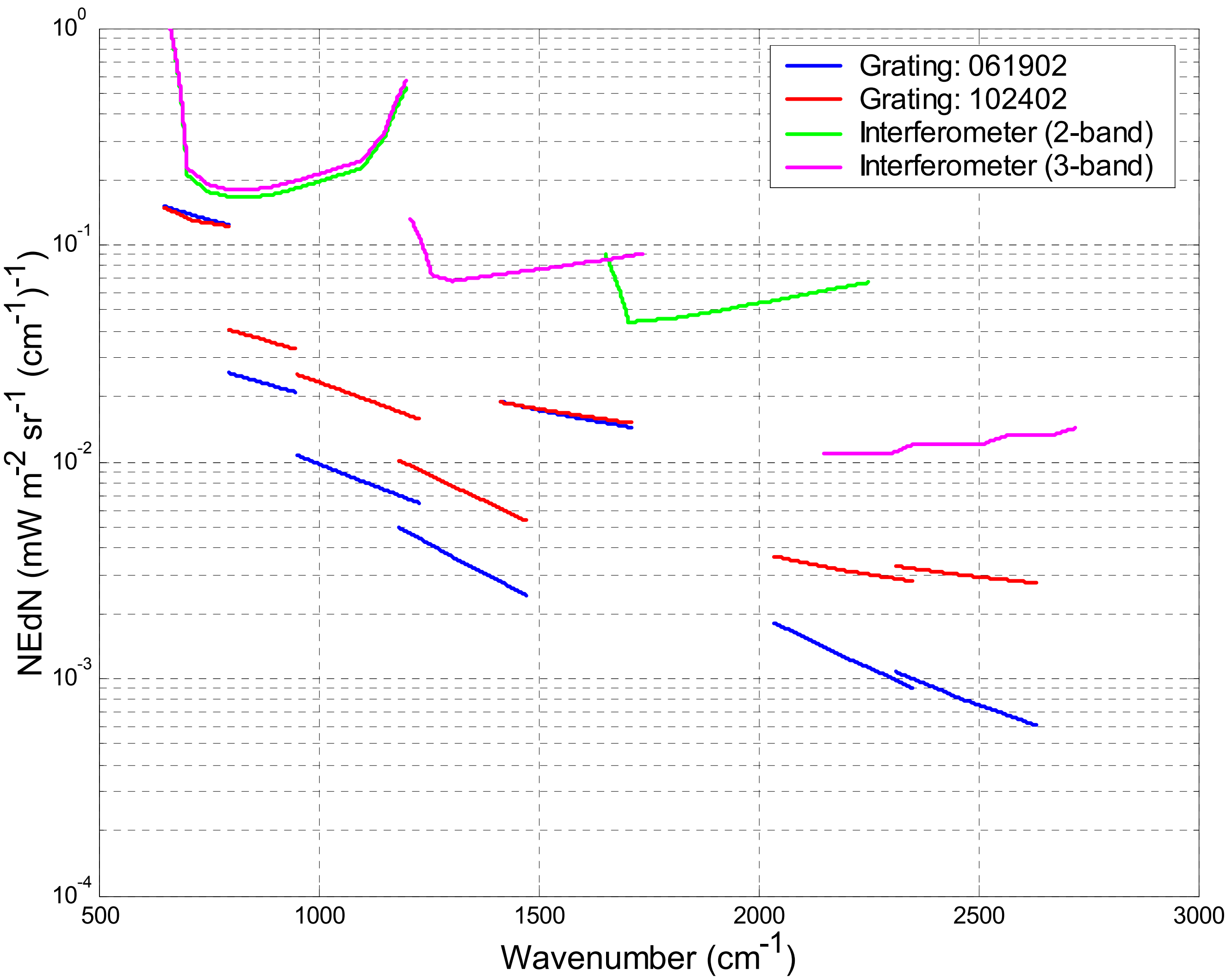
NE∆N



"102402" grating NE∆N includes contributions from chopper and 8 detector elements per spectral bin (for improved Detector Optics Ensquared Energy (DOEE))

IASI Rapid Transmittance Algorithm

- ~0.25 cm^{-1} spectral resolution
- 9230 channels (605.095 – 2829.96 cm^{-1})
- Truncated-Gaussian apodization function (FWHM ~0.5 cm^{-1})

ABS radiances were computed by fitting IASI spectral response functions (SRFs) to a "template" function:

- Gaussian/Lorentzian hybrid for grating

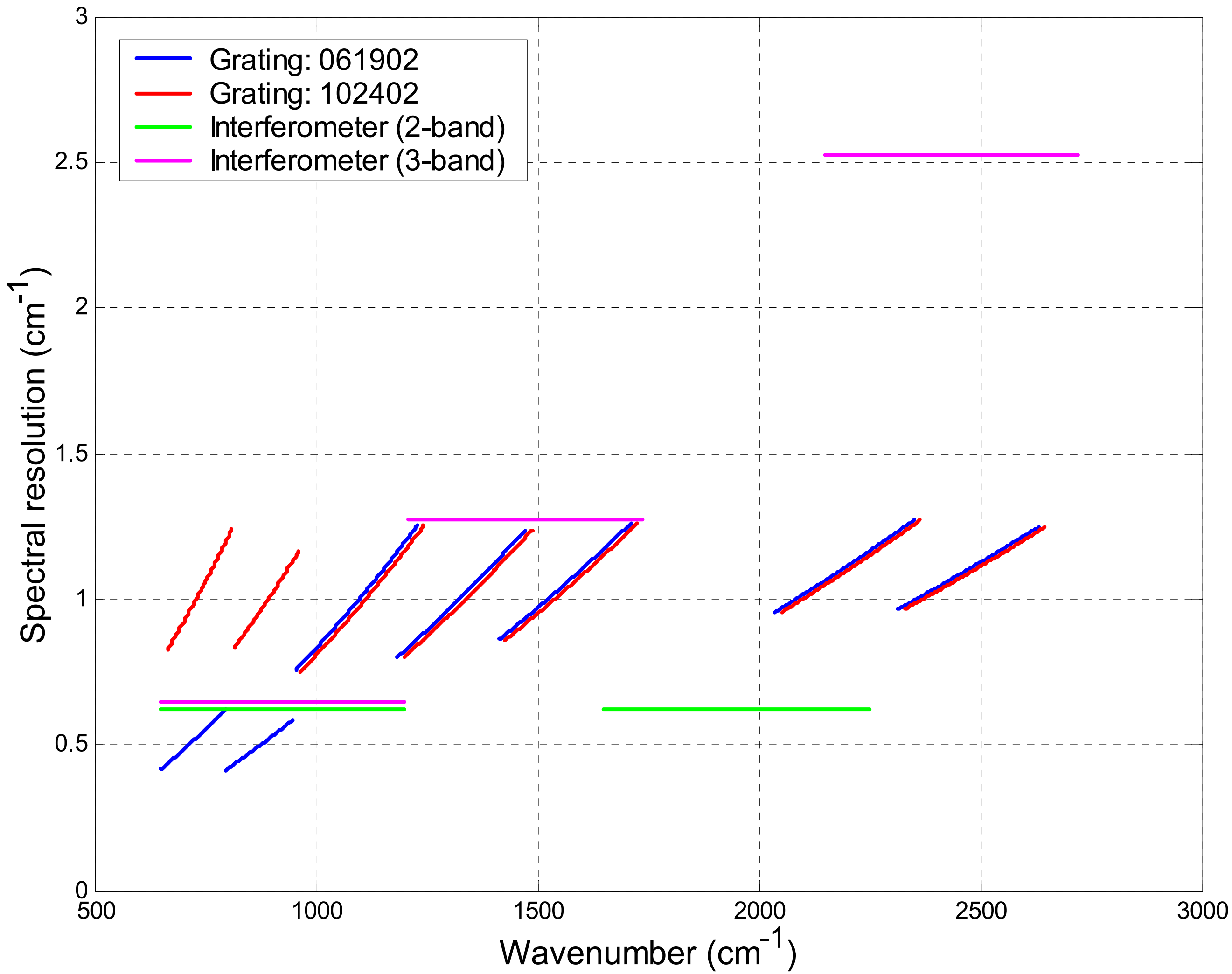
$$SRF(x) = g_f(e^{-\log(2)x^{(2+g_s x)}}) + (1-g_f)(\frac{1}{1+x^{L_e}})$$

where $x = \frac{2|\nu - \nu_i|}{\gamma_i}$ and γ_i is the FWHM of the SRF

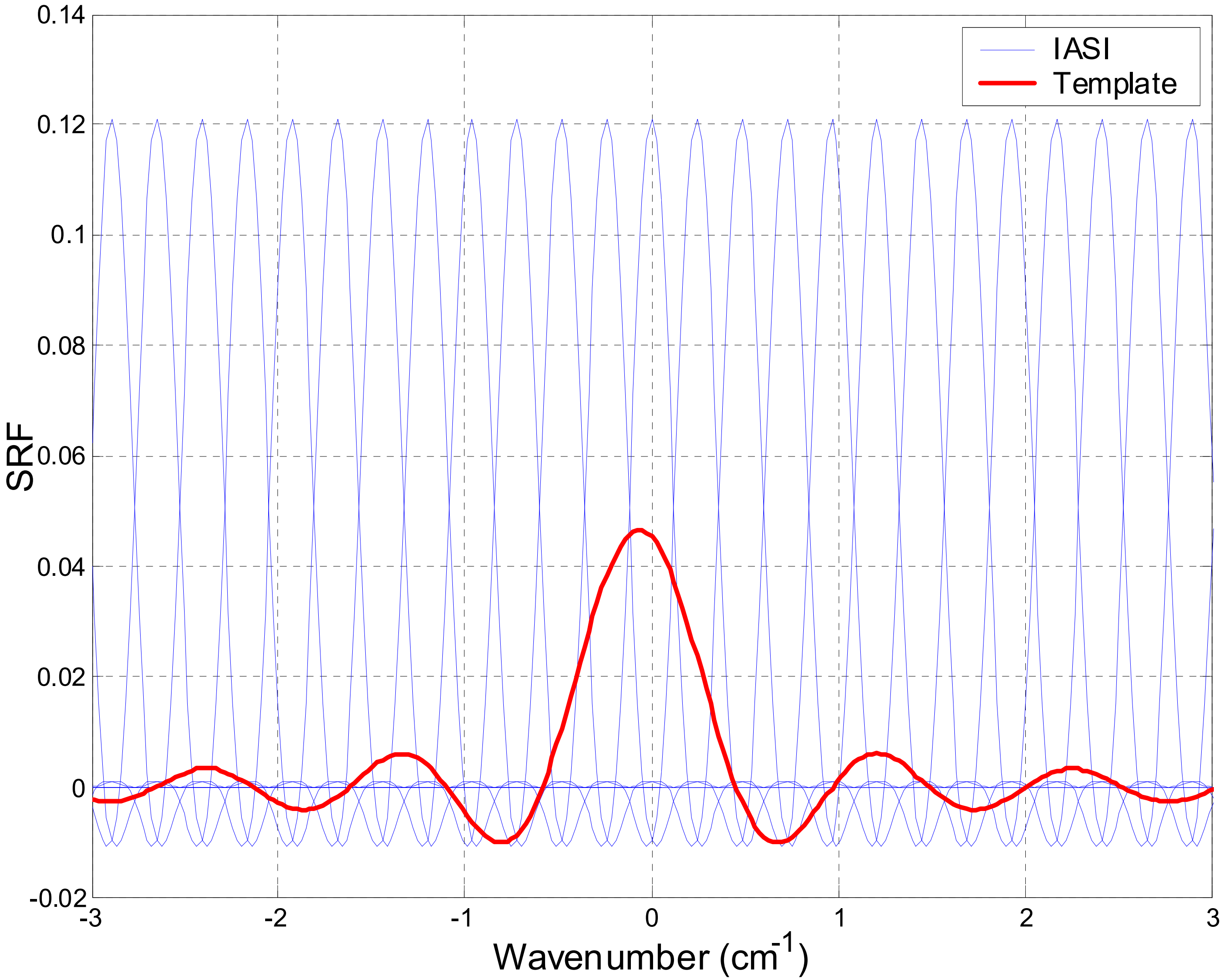
- Unapodized sinc for interferometer

typically: $g_s \approx 0.5,\ g_f \approx 0.95,\ L_e = 1.8$

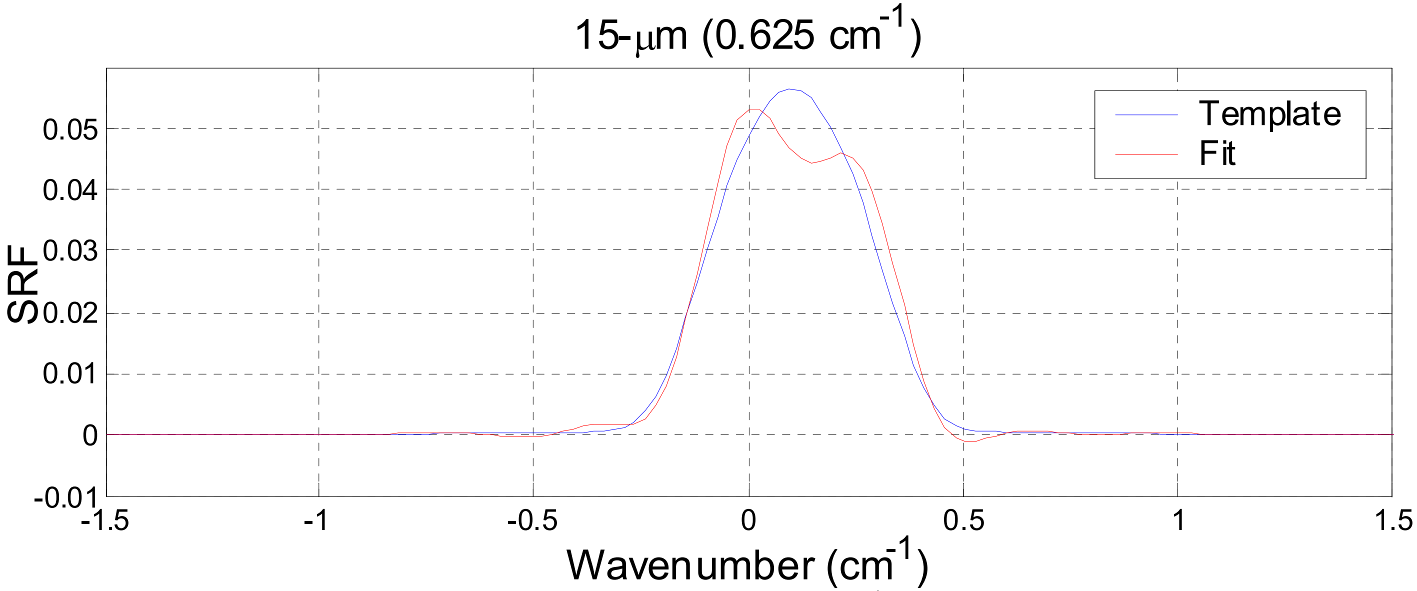
Spectral Resolution

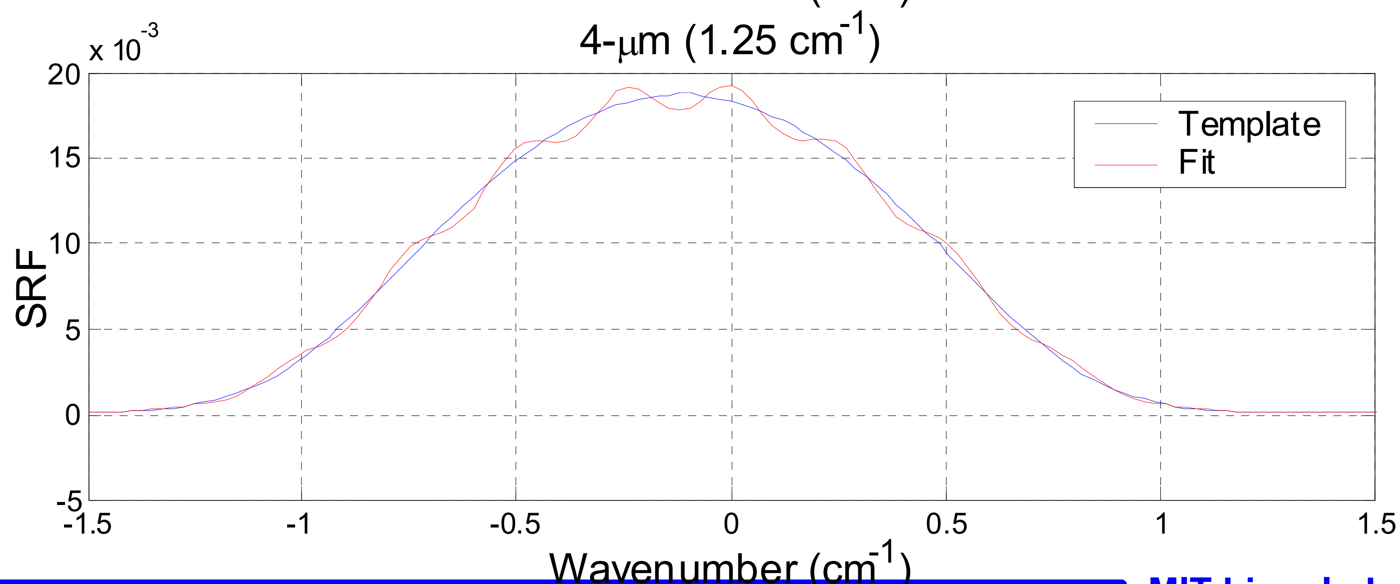


Synthesis of Spectral Response Functions

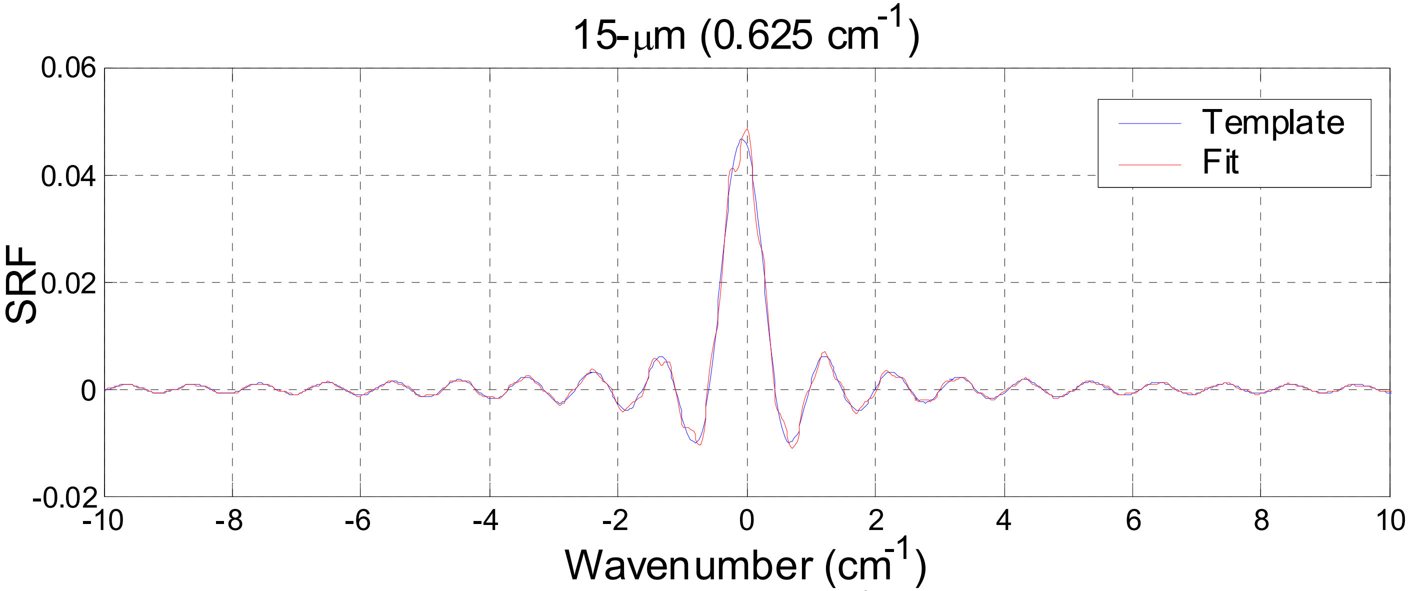


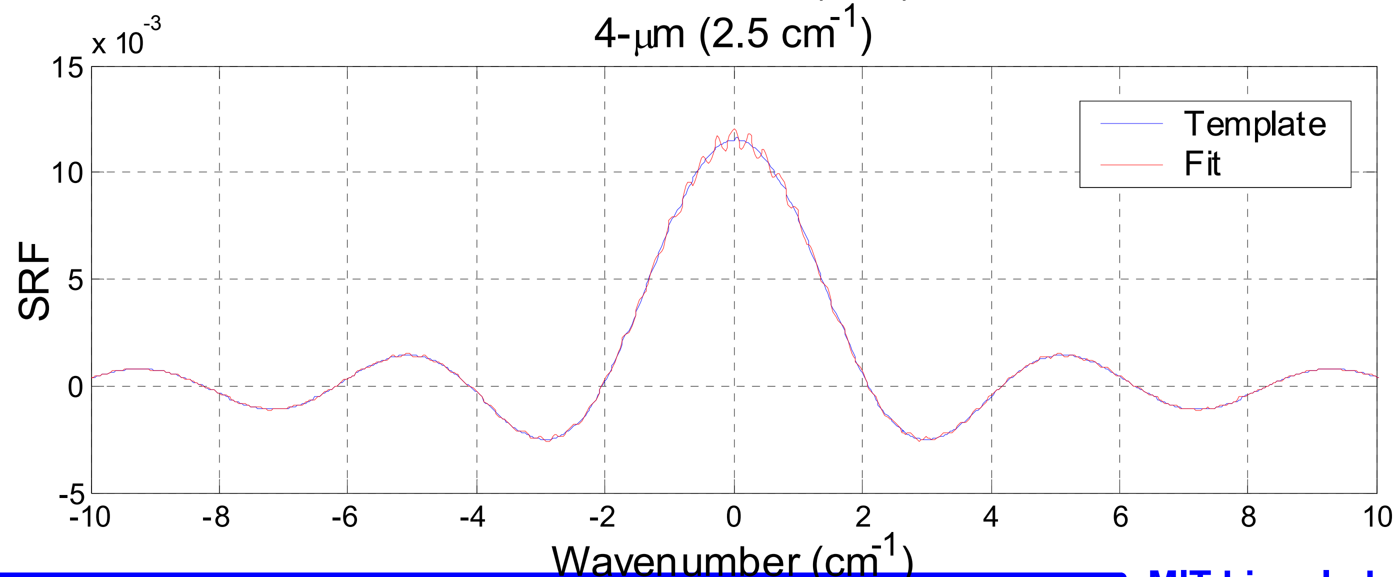
Example: Synthesis of Grating SRFs





Example: Synthesis of Interferometer SRFs





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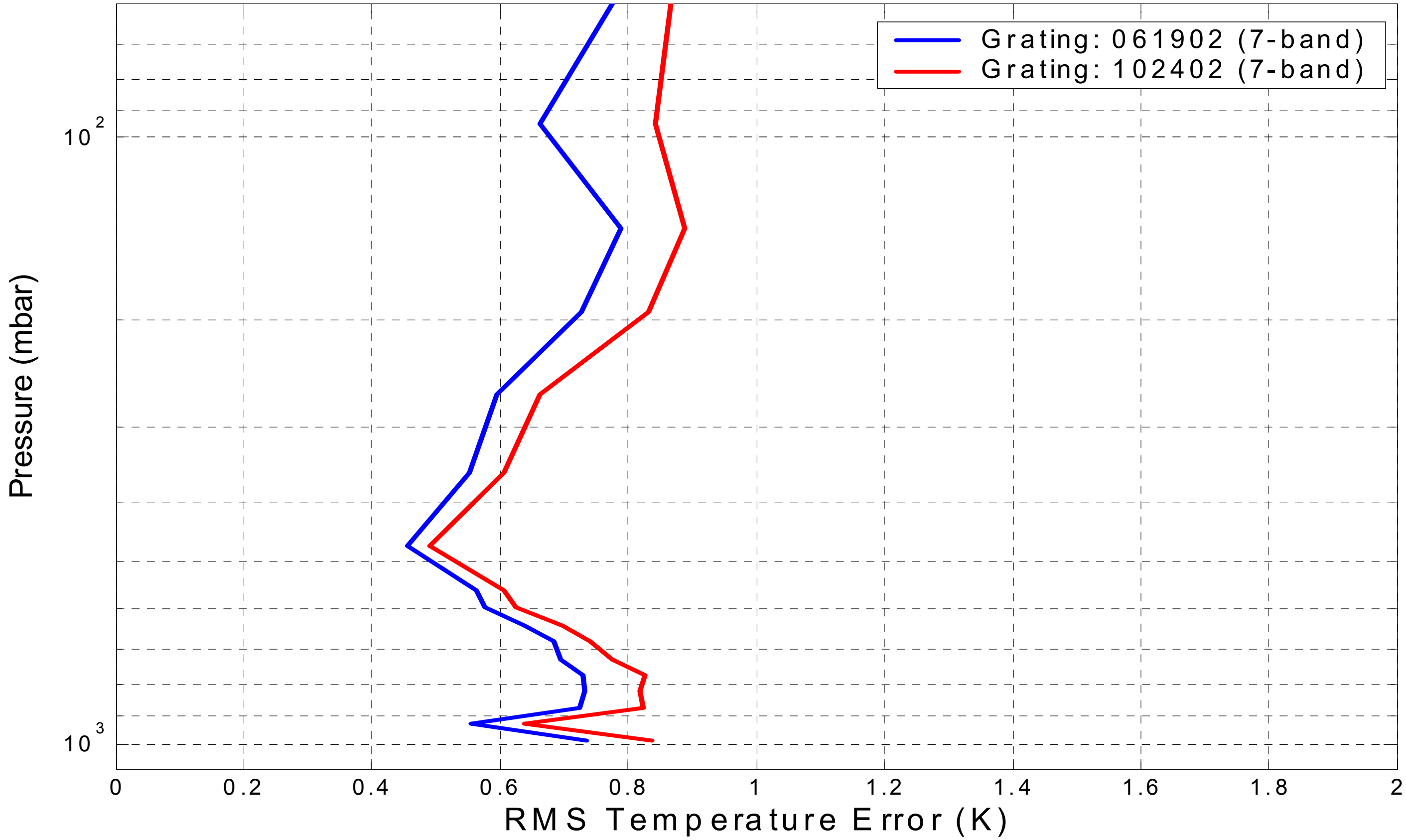
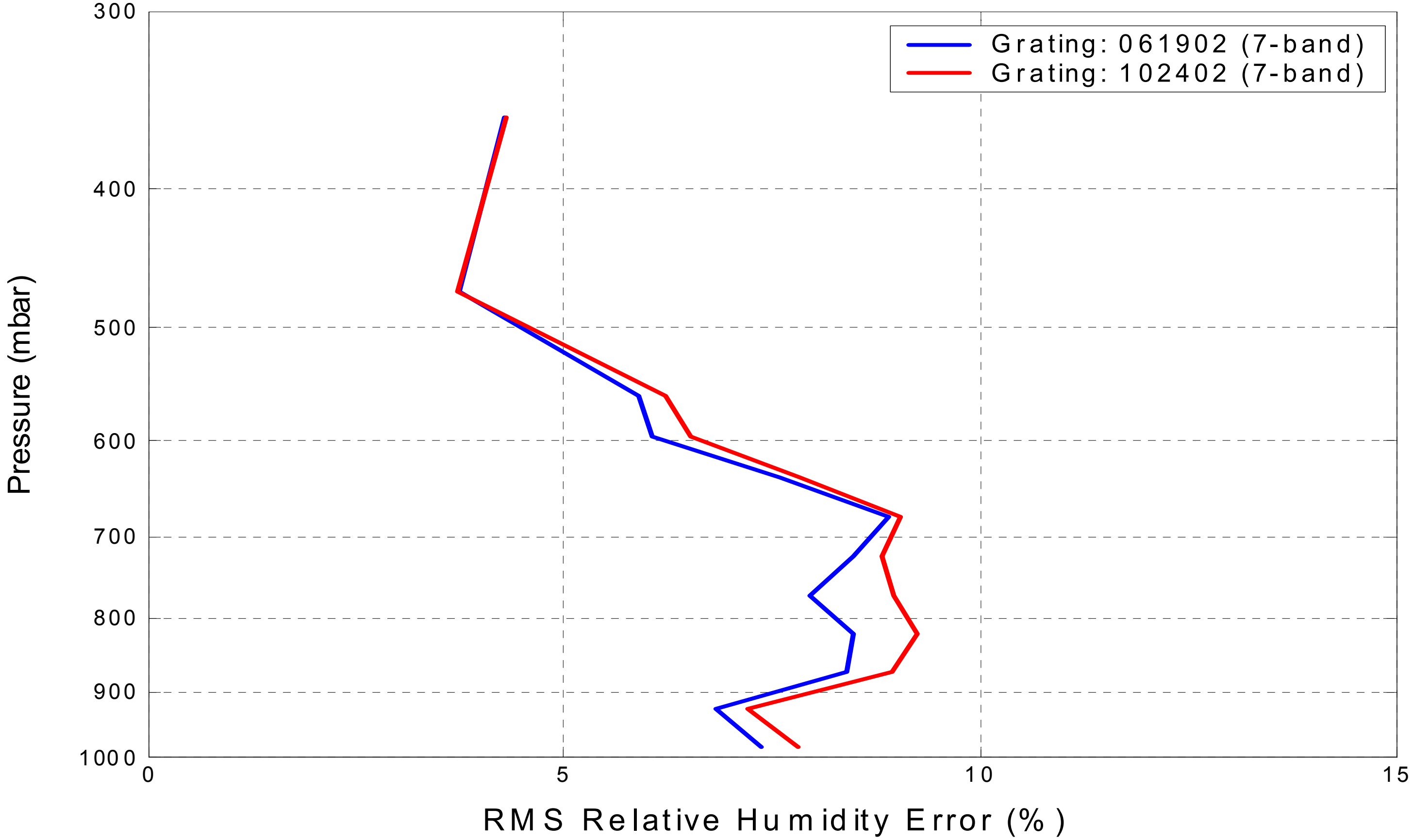
Grating: Temperature Retrieval



Changes from “061902” design include:

1. Degraded longwave spectral resolution
2. Chopper
3. 8-detectors per spectral element

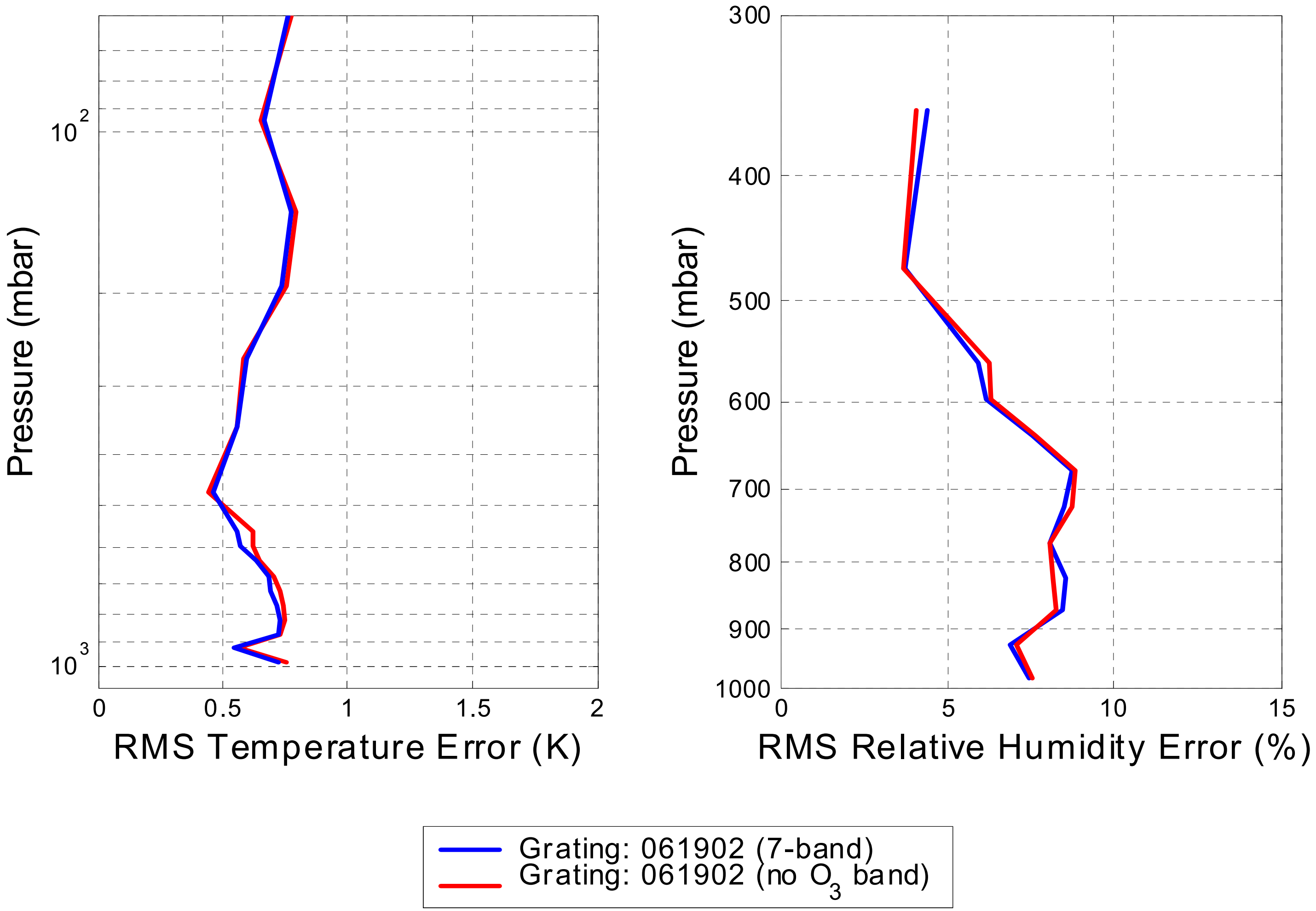
Grating: Water Vapor Retrieval



Changes from "061902" design include:

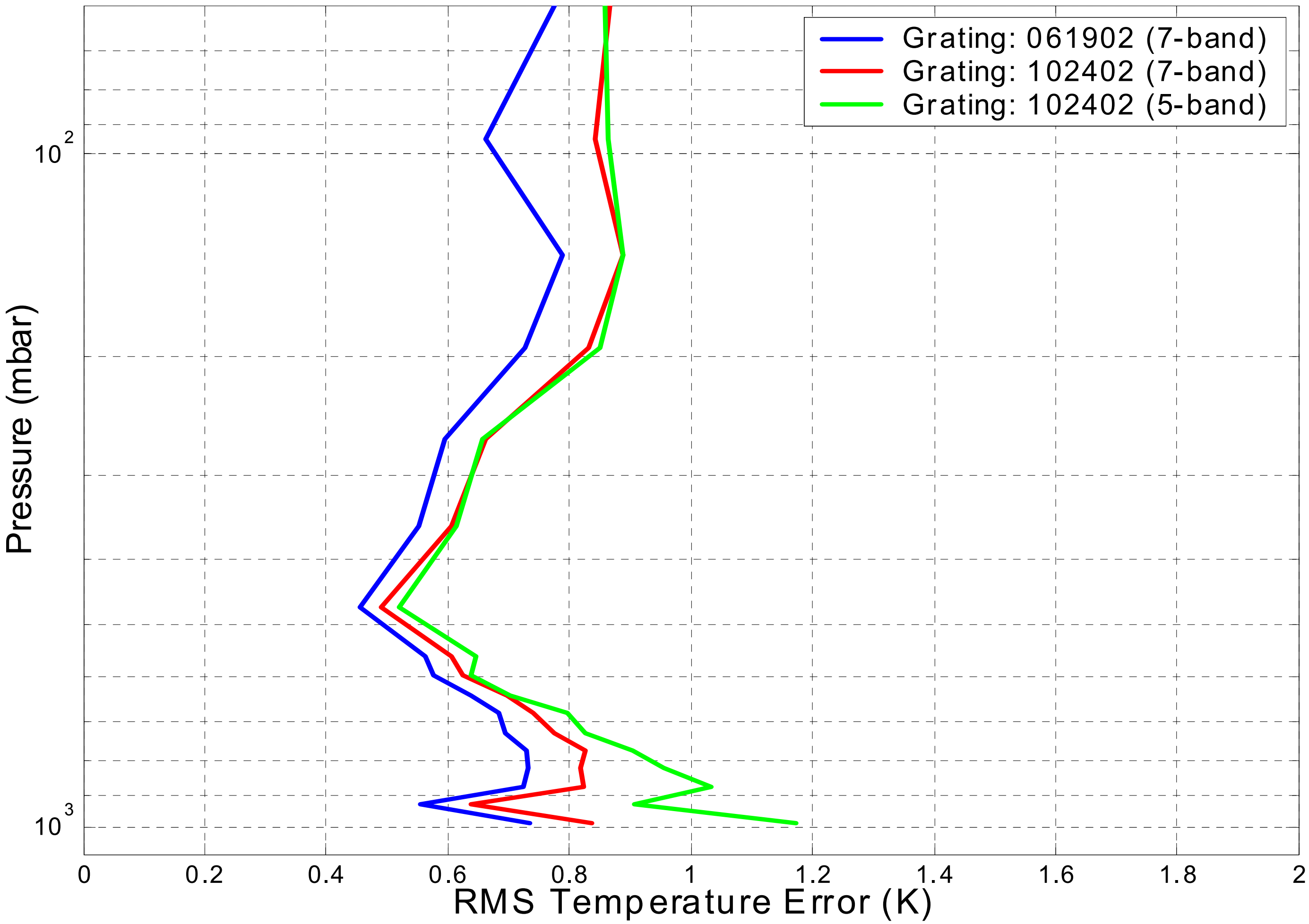
1. Degraded longwave spectral resolution
2. Chopper
3. 8-detectors per spectral element

Grating: Retrieval Performance with/without Ozone Band



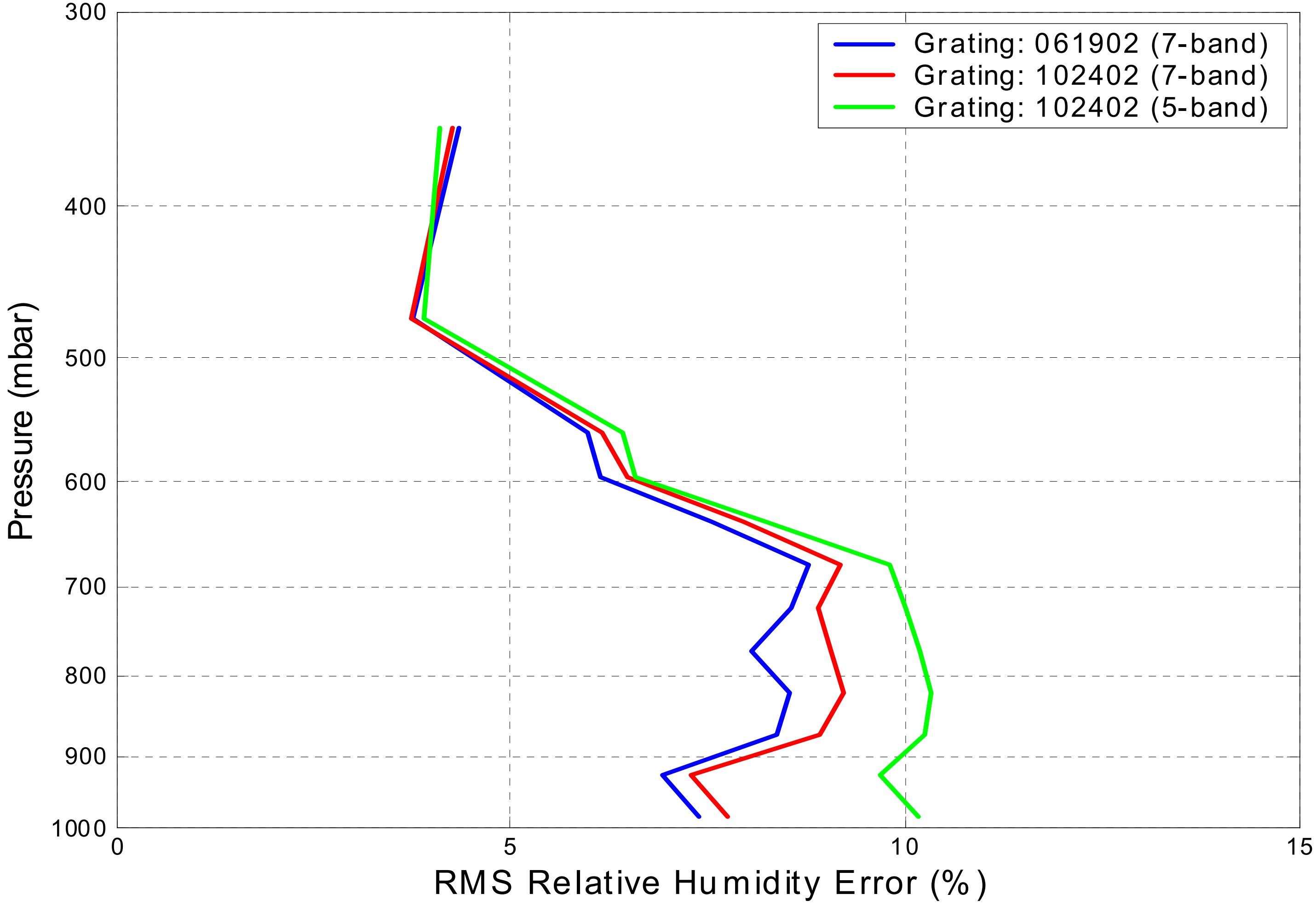
- Ozone band has negligible impact on temperature and water vapor retrieval

Grating: Impact of Shortwave Bands on Temperature Retrieval



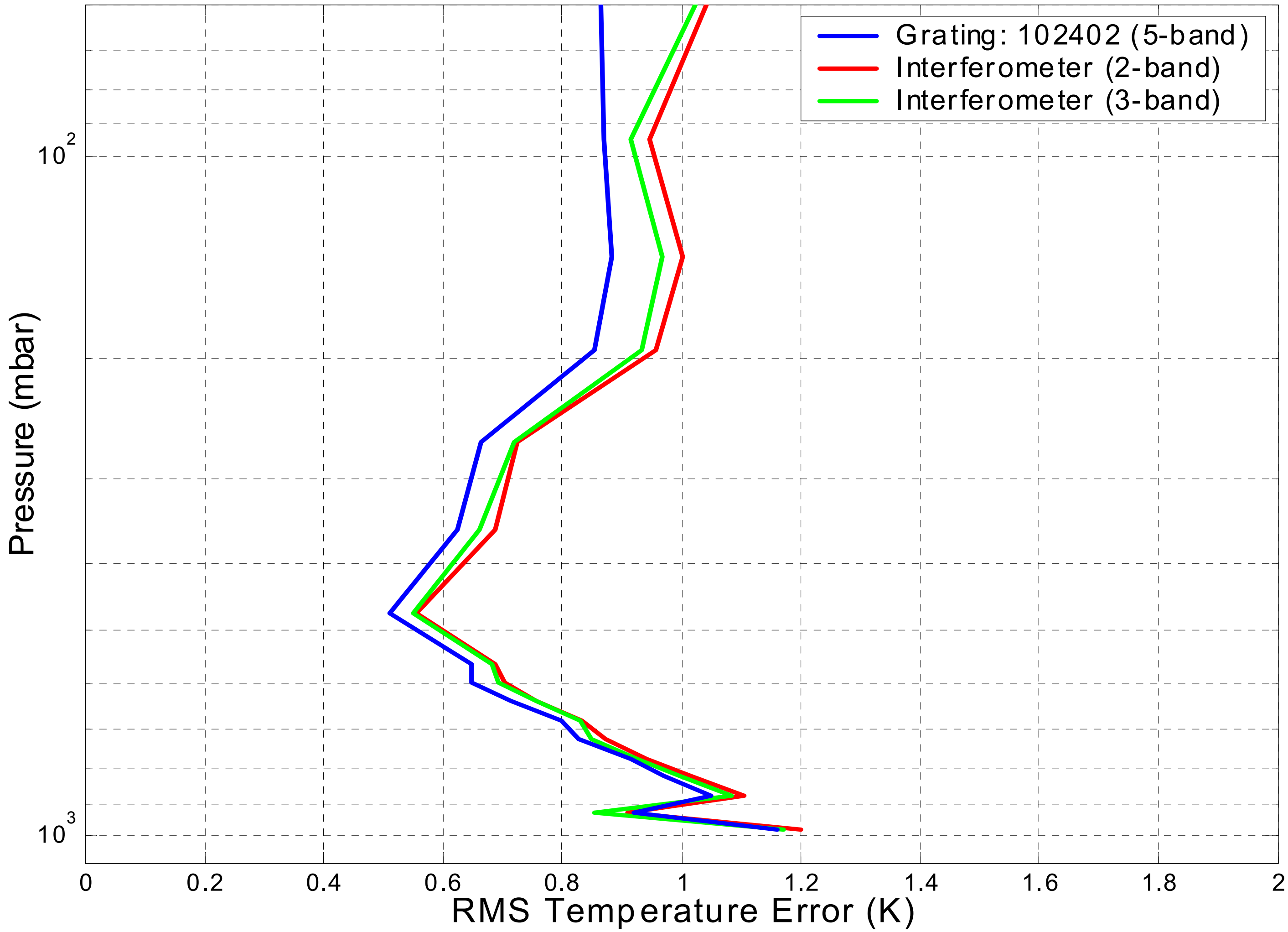
- Removal of SW bands has significant impact near surface
- Performance still close to 1K specification

Grating: Impact of Shortwave Bands on Water Vapor Retrieval



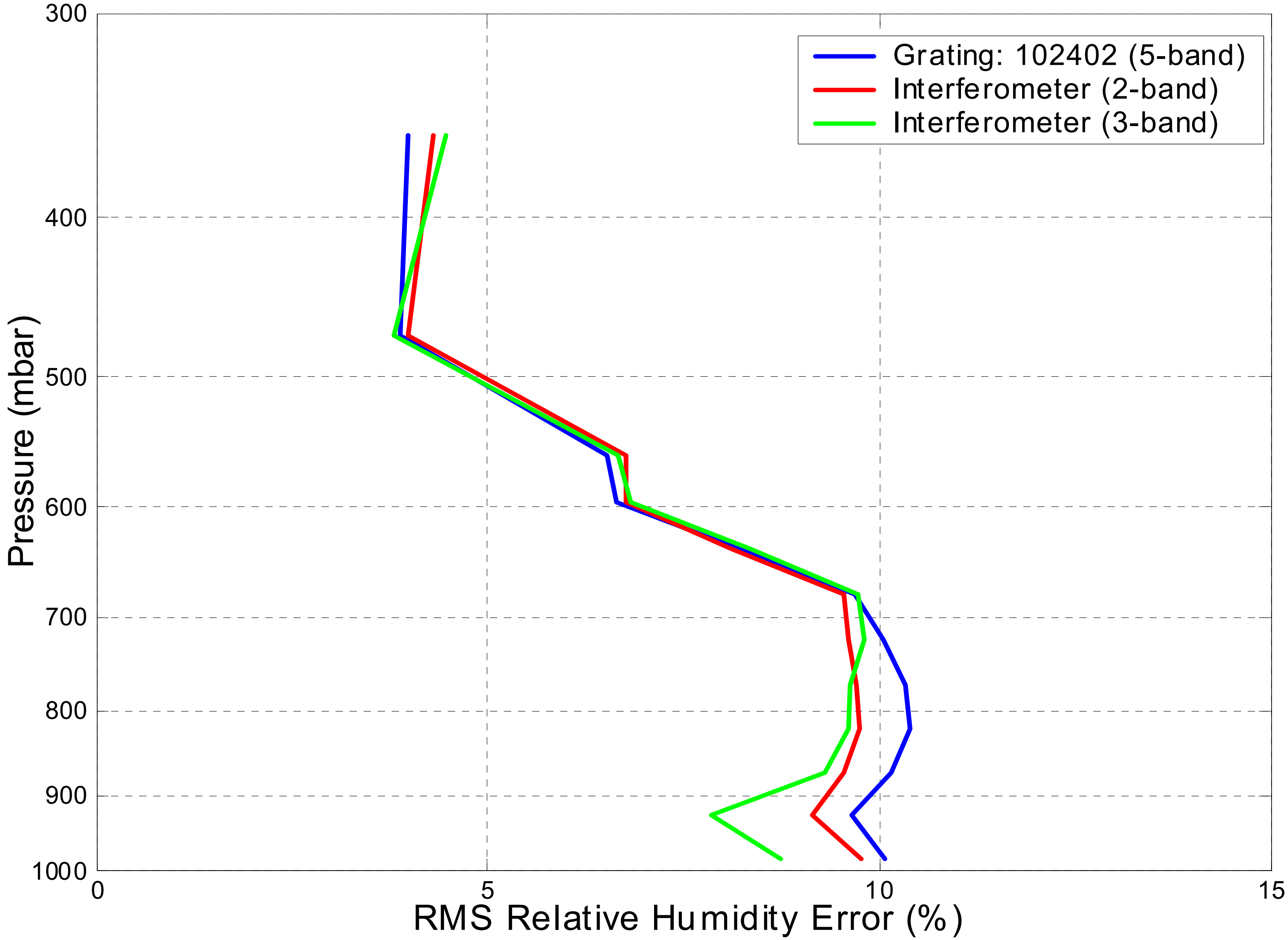
- Removal of SW bands has significant impact near surface
- Performance still close to 10% specification

Grating vs. Interferometer: Temperature



- New 5-band grating design meets or exceeds both 2-band and 3-band FTS designs

Grating vs. Interferometer: Water Vapor



- New 5-band grating design slightly worse than FTS, but almost meets 10% specification

Outline

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  - Impact of degraded spectral resolution
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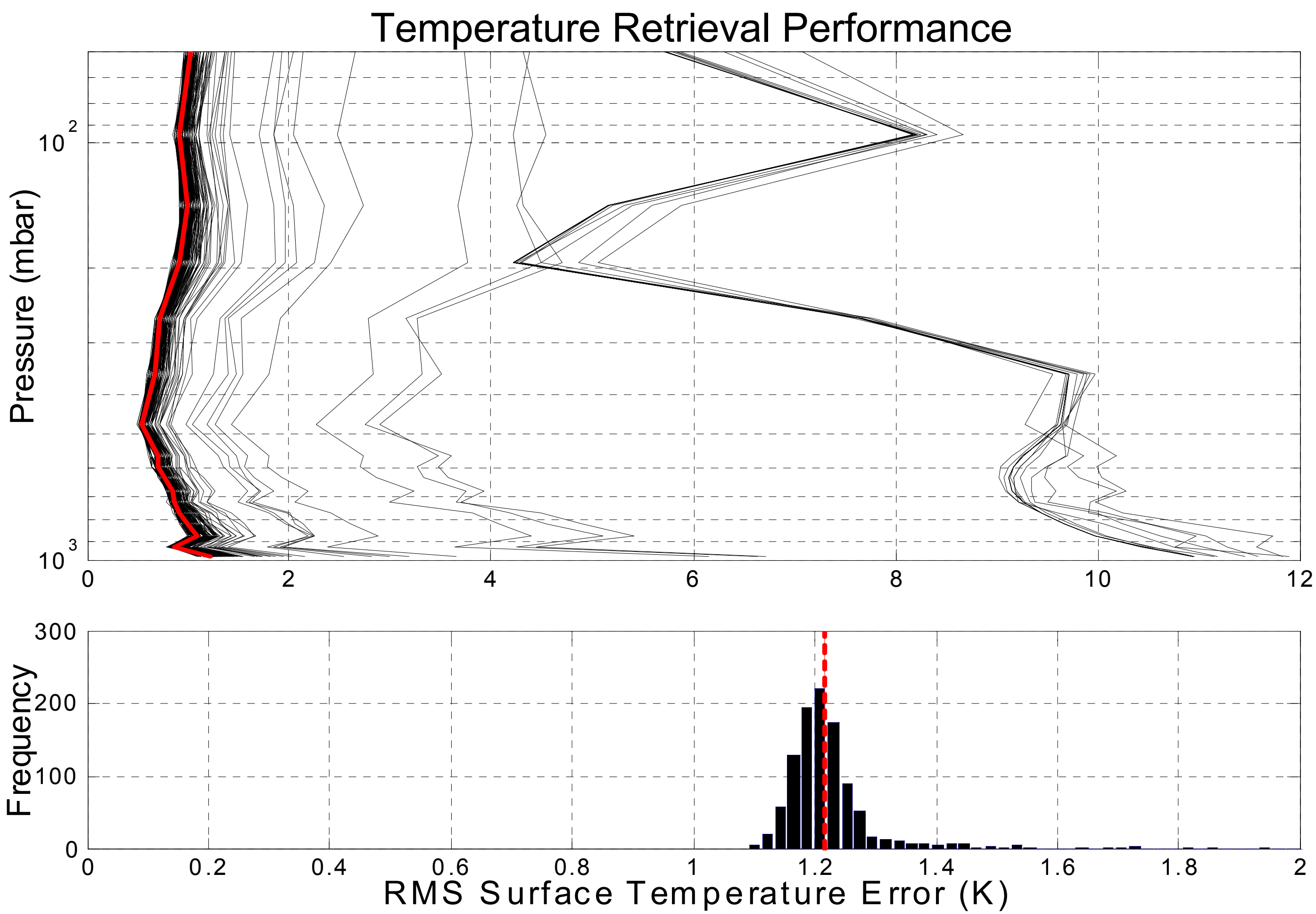
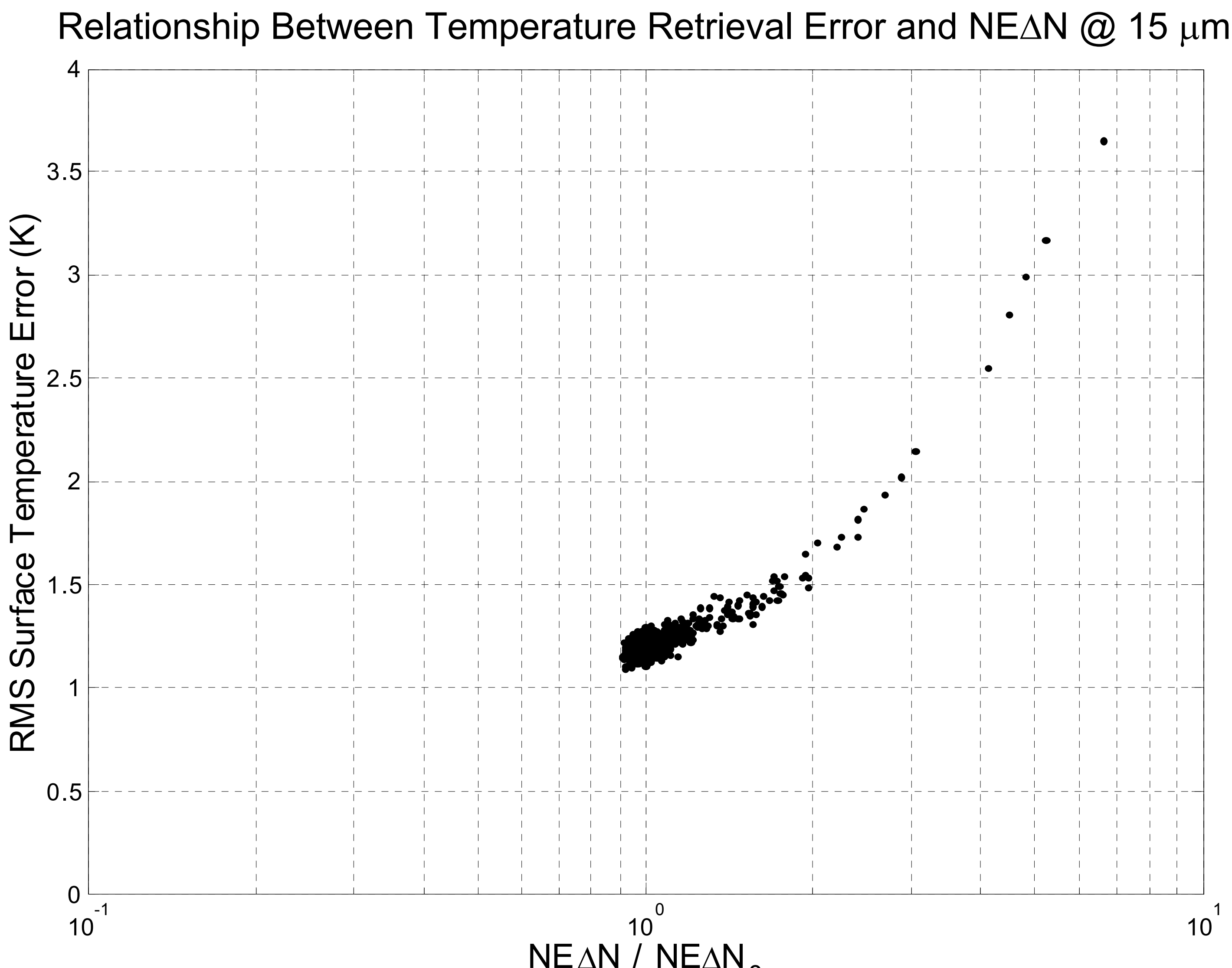
- ➢ *Preliminary Operability Analyses*
  - Interferometer
  - Grating

3-Band Interferometer: Operability Study

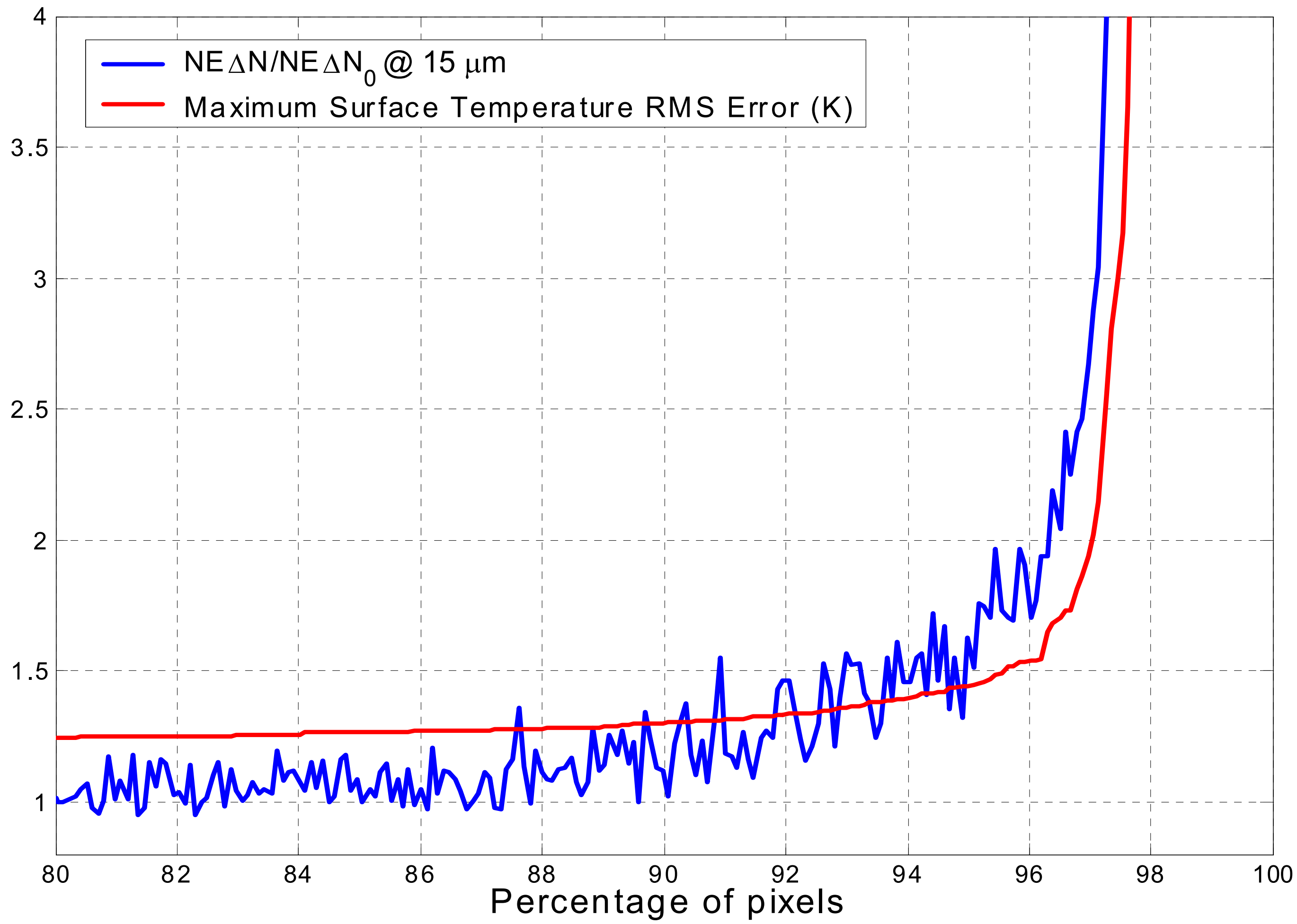


Measurements of 1057 detector elements were used in a Monte Carlo simulation
Median curve (used in previous analyses) shown in red for reference

3-Band Interferometer: Operability Study



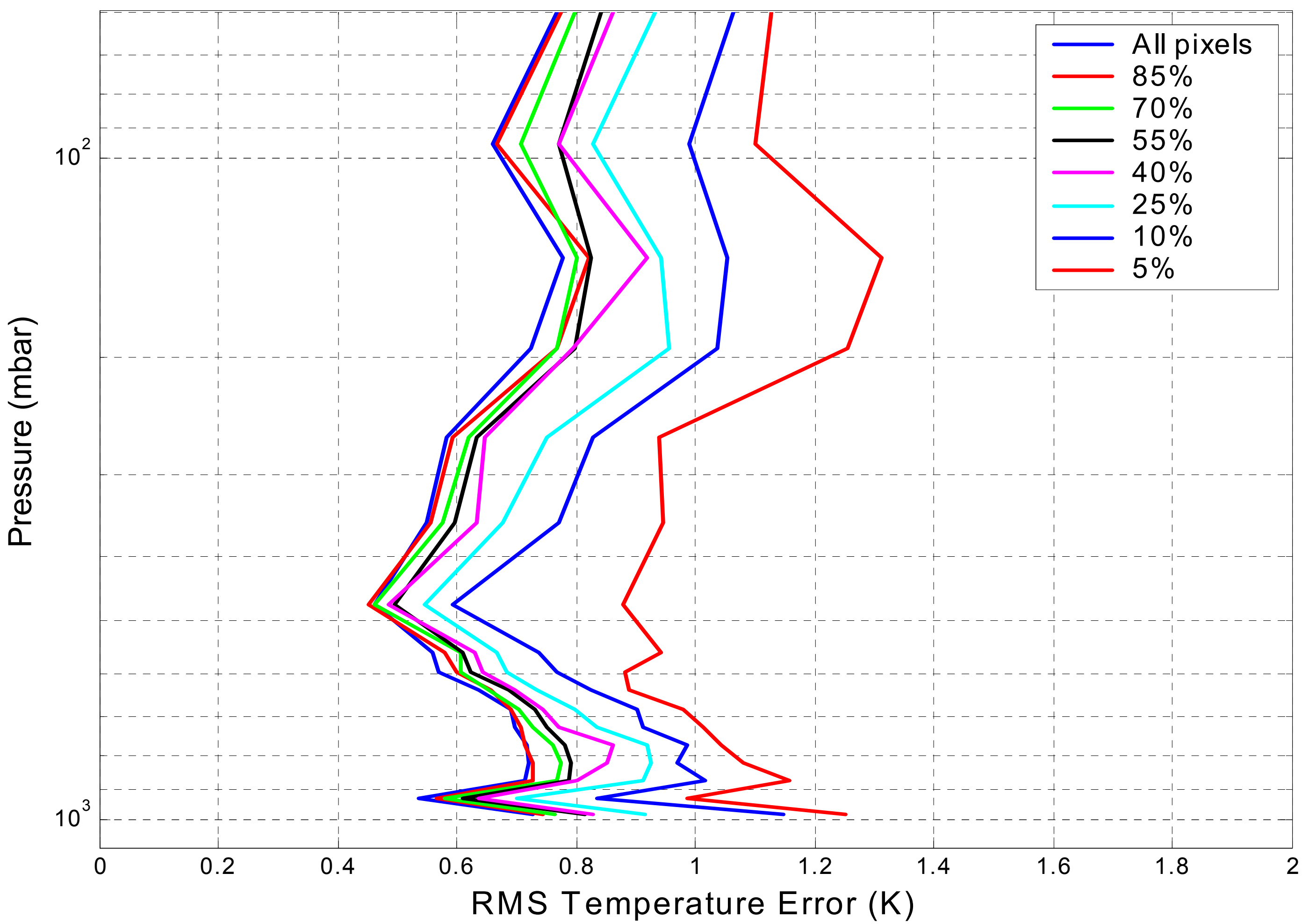
3-Band Interferometer: Operability Study



Two (related) metrics can be derived for thresholding performance

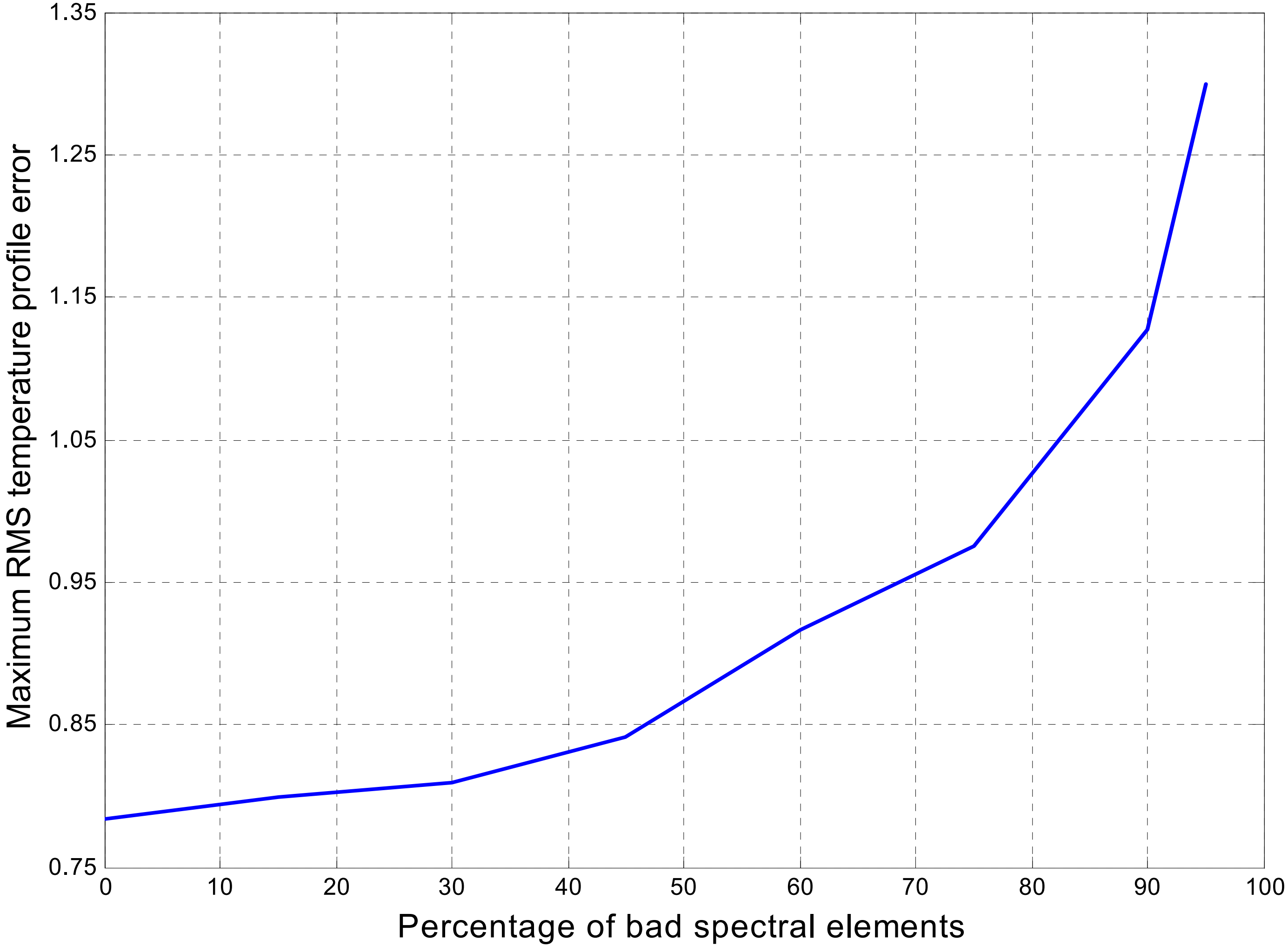
Example: Limit of 20% above nominal retrieval performance excludes pixels with NE∆N > 2*NE∆N_0

Grating: Operability Study



- Grating very insensitive to spectral pixel failure

Grating: Operability Study



Summary

- **Impact of employing new baseline for high DOEE is minimal.**
  - Assumes resolution is degraded to 1.25 cm^{-1} (max) in all wavebands
- **Two-band interferometer performance, currently considered sufficient for ABS, is almost identical to that of the grating ABS with five bands (LWIR and MWIR).**
  - 1.25 cm^{-1} resolution (max) across the water vapor band (reduced compared to 2 band ABS)
  - 1.25 cm^{-1} resolution (max) across the ozone feature
  - Temperature and water vapor retrieval performance similar to 2-band and 3-band interferometers
  - Reduced resolution proposed to NOAA
- **Operability:**
  - Benchmark curves can be used to choose FTS LW focal plane operability requirement based on performance in retrieval space.
  - Preliminary results show grating performance weakly dependent on focal plane operability – further study is required.

DOEE Portion of a presentation to NOAA

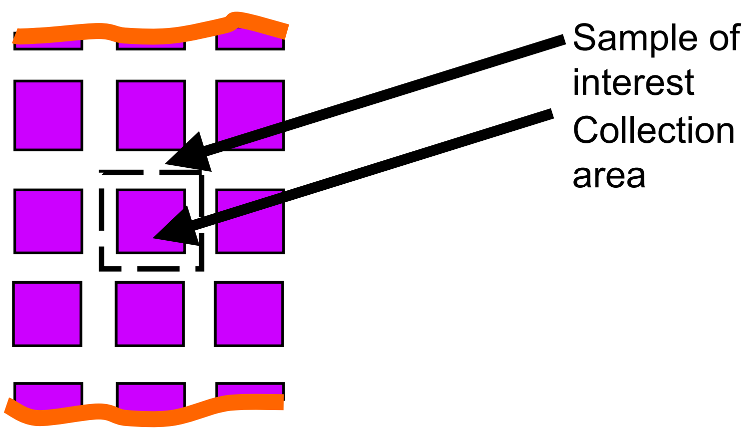
Monica Coakley, Danette Ryan-Howard and Bill Blackwell

GOES Quarterly Review

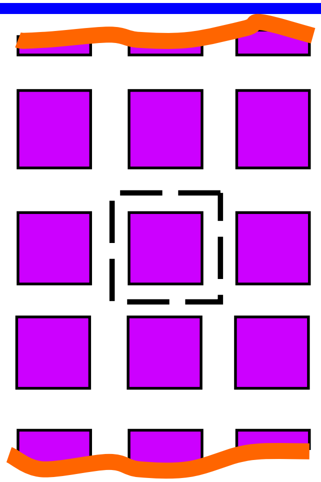
22-24 October 2002

Detector-Optics Ensquared Energy (DOEE) in July 2002 HES TRD

- **DOEE values of 90% or better are desired by NOAA scientists, but have to be achievable**
- **The detector-optics ensquared energy (DOEE) is essentially the ensquared energy (EE) reduced by the diffusion crosstalk**
  - **Diffusion crosstalk can be significant unless efforts are taken to mitigated it, as in the most recent LL interferometric point design**
  - **Mitigation reduces the total flux to the detector**
    - **Implementation method in that design is not common in industry and may not completely eliminate diffusion crosstalk**
    - **HES portion of MRD reduces the calculated EE by ~2% for the DOEE values.**



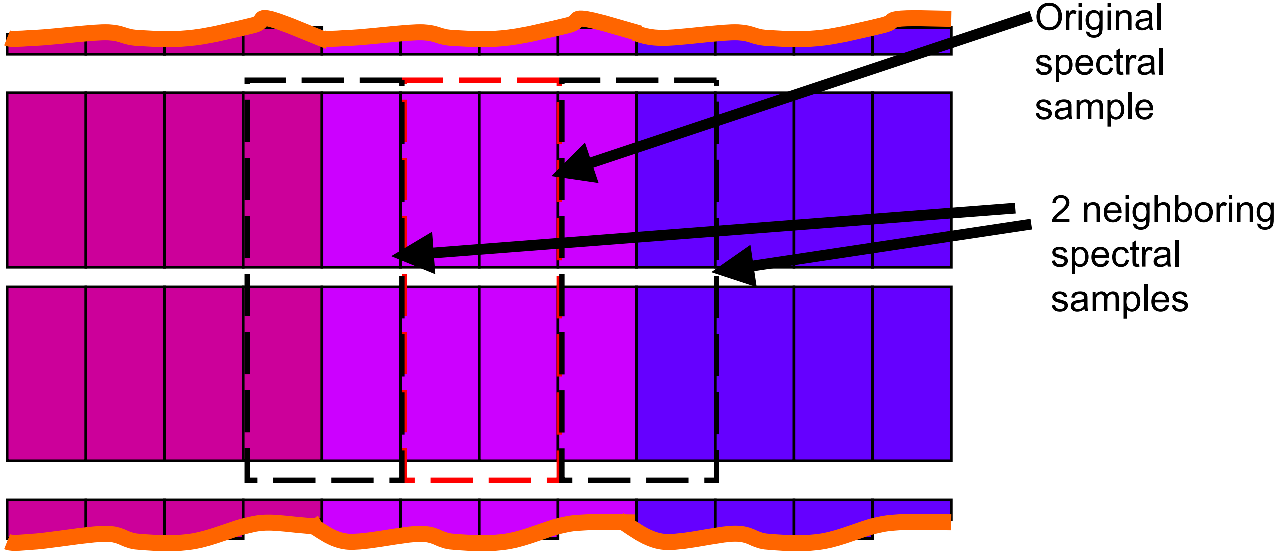
Modeling of DOEE for Interferometric System



- **Modeled EE:**
  - Rays originating from a single ground spot were traced through the optics to the FPA
  - EE is calculated ratio (in percent) of rays making it to the pixel of interest after diffraction to the total number of rays originating from the ground spot (original design)

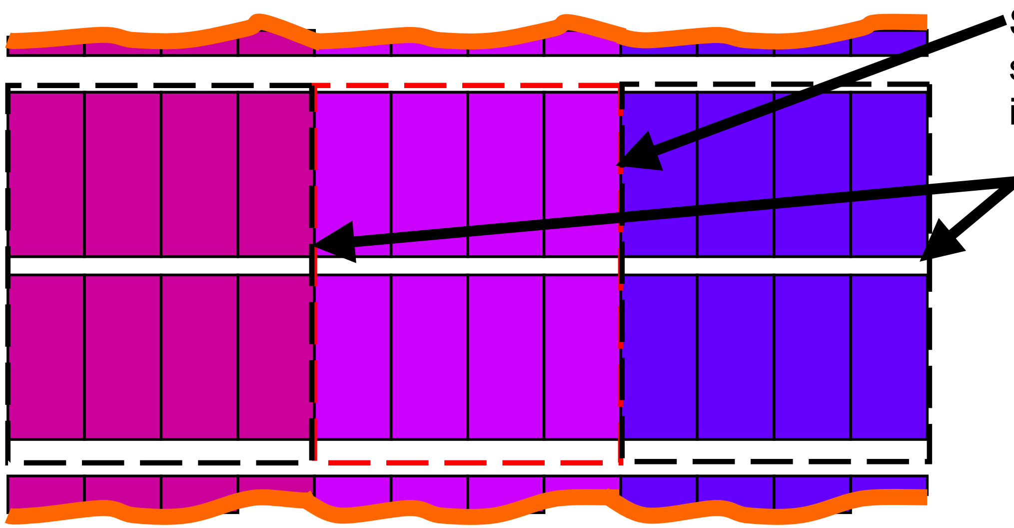
- **Modeled DOEE for 4 km ground patch:**
  - Despite high DOEE, only 18% of the light from the ground spot at 13 um and 21% at 6 um reach the detector

Modeling of DOEE for Dispersive System



- **The same modeling methodology was used for the June, 2002 dispersive system**
  - **50 % of light impinged on original FPA pixel of interest at 13 um**
  - **3 % went into the top or bottom neighbors, reducing the EE at 13 um**
  - **EE is 0.96, DOEE is 0.94**
  - **25 % went into the left or right side neighbors, reducing the spectral purity to 66.6%.**

Modeling of DOEE for Dispersive System (cont'd)



Note: Larger spectral samples to capture more of diffraction pattern

- **The same modeling methodology was used for the October, 2002 dispersive system**
  - **EE is 0.96, DOEE is 0.94**
  - **8 % went into the left or right side neighbors, reducing the spectral purity to 91% before crosstalk.**
- **High DOEE appears obtainable from a 10 km x 4.2 km pixel, so propose >90% for all 10 km cases.**
- **Diffusion inside the pixel causes crosstalk to the neighboring pixels, reducing spectral purity in this geometry by ~9% based on lab measurements.**

Modeled DOEE and Spectral Purity for Dispersive System

- Calculated DOEE including minimal correction for crosstalk in top and bottom pixels
- Spectral Purity
  - In the retrieval modeling, 7% spectral contamination was assumed.
  - Diffusion crosstalk to right and left neighbors for this geometry reduces spectral purity by ~9%.
  - Optical modeling gives additional 9%
  - Thus retrieval spectral profile must be modified by to account for a factor of 1.6 times more spectral contamination to correctly account for the optical and diffusion effects totaling 18% with spectral purity of 82%.